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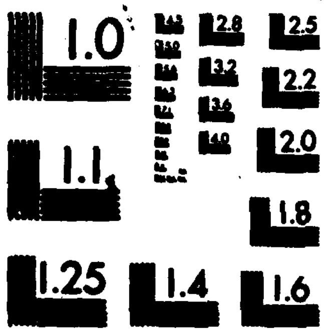

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ON-SITE FUEL CELL APPLICATION ANALYSIS

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AD A129388

FEBRUARY 1983

FINAL REPORT FOR THE PERIOD SEPTEMBER 1981 TO DECEMBER 1982

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

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This program evaluated the energy conservation and economic potential of on-site fuel cell service for Air Force Logistic Command Facilities. Numerous facilities were examined at Wright-Patterson AFB, Hill AFB, and Robins AFB. One facility was selected at each base for detailed benefit and integration analyses. Results of the analyses are presented.

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FOREWORD

This final report is submitted by United Technologies Corporation under Contract F33600-81-C-0582. This effort was sponsored by the Aero Propulsion Laboratory Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio and the Directorate of Operations and Maintenance, Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio. Captain Richard G. Honneywell was the Project Engineer for the Aero Propulsion Laboratory and Major George Kastanos was the Project Manager for the Air Force Logistics Command. Mr. Joseph W. Staniunas, of United Technologies Corporation, was the Principal Investigator.

The author acknowledges the contributions of the following persons who provided valuable input, comments and suggestions for this application analysis: Major George Kastanos, Captain Richard Honneywell, Donald Seiling (Wright-Patterson AFB), Lamont Nelson, Robert Hanson (Hill AFB), Gaither B. Lane (Robins AFB) and James K. Stedman, Paul J. Farris, Gerald P. Merten (United Technologies Corporation, Power Systems Division).

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Section 1
EXECUTIVE SUMMARY

Recent Presidential and Congressional directives require the Department of Defense to implement programs which will limit petroleum consumption through increased conservation and the use of alternative fuel sources. Energy self-sufficiency goals have also been issued by the Air Force Logistics Command (AFLC) for its Air Logistics Centers. Through their in-house and contracted analysis, the Air Force Systems Command has identified fuel cell on-site energy conversion systems as a potential superior method to satisfy these requirements.

It was the objective of this study to evaluate the energy conservation and economic potential of on-site fuel cell energy service for Air Force facility applications. Thirteen facilities have been identified among three Air Force Logistic Command Bases as possible test sites of a 40-kW on-site fuel cell energy system. Collectively these sites represent a wide diversity of Air Force applications. Individually each site exhibits characteristics which make it a uniquely viable candidate test site. A conceptual integrated system design is provided for each recommended site.

The following facilities are recommended for further evaluation as fuel cell test sites:

Base	Facility
Wright-Patterson AFB:	Air Force Museum
Hill AFB:	Airmen's dormitory
Robins AFB:	Central steam plant

The selection criteria for these sites included a measure of the degree to which available fuel cell thermal output was utilized and an estimate of the projected operating savings for each site.

In the study it is assumed that the 40-kW fuel cell power plant is connected to the utility grid and operated continuously at full power. The amount of fuel cell heat recovered and utilized ranges from 38 to 89% among the thirteen sites. Average heat utilized is 64%. Due to the high thermal and electric utilization of the fuel cell at these sites the operating cost savings are high and do not vary significantly from one site to another within a given base.

TABLE 1-1. FUEL CELL ANALYSIS SUMMARY

Base	Facility	Fuel Cell Thermal Use	Fuel Cell Heat Utilized ~%
Wright-Patterson AFB (Ohio)	Headquarters	dhw (domestic hot water)	57
	Officer Quarters	dhw	55
	Officer Quarters	dhw	54
	Gymnasium	dhw & pool heating	79
	*Museum	space heating	70
	Heating Plant	feedwater heating	49
	Cafeteria	dhw & dishwashing	38
	Dining Hall	dhw & dishwashing	61
Hill AFB (Utah)	Medical Center	dhw	61
	*Airmen Dormitory	dhw	50
	Hospital	dhw	75
Robins AFB (Georgia)	Plating Shop	process heating	89
	*Steam Plant	feedwater heating	89

*Selected for conceptual integration system design

In addition to high thermal utilization in these applications, the fuel cell system design provides other, perhaps more important, benefits. For example, if the electric utility grid is disrupted, the fuel cell energy system is designed to operate isolated from the grid. In this way, critical Air Force electric loads can remain operational with high reliability. High reliability is assured since the backup generator (the fuel cell) is already operating at full power and need only to switch over to the designated isolated critical loads. In addition having the fuel cell system connected to the electric utility grid assures 100% utilization of the power plant electrical output. Electricity generated in excess of that required at the sited facility can be utilized within the base confines, thus reducing the net base electric bill. Other important benefits associated with on-site fuel cell co-generation are noted in Figure 1-1.

It is anticipated that the actual testing of fuel cell power plants in Air Force applications will be preceded by a period of facility data monitoring and evaluation. The resulting energy consumption patterns in each of the applications will ultimately determine the most effective fuel cell thermal system configuration. The baseline conceptual thermal integration designs suggested in this report should help focus the data monitoring activity to those facility loads most likely to benefit from integration with the 40-kW fuel cell power plant.

FUEL CELL COGENERATION OFFERS:

- OVERALL UTILITY COST SAVINGS
- CONSERVATION OF NATURAL RESOURCES
- HIGH RELIABILITY, AVAILABILITY FOR NORMAL AND EMERGENCY GENERATION
- QUIET, LOW EMISSION OPERATION

Figure 1-1. Fuel Cell Benefits at Air Force Logistic Command Bases

Section 2
INTRODUCTION

Recent Presidential and Congressional directives require the Department of Defense to implement programs which will limit petroleum consumption through increased conservation and the use of alternative fuel sources. Energy self-sufficiency goals have also been issued by the Air Force Logistics Command (AFLC) for its Air Logistics Centers. Through their in-house and contracted analysis, the Air Force Systems Command has identified fuel cell on-site energy conversion systems as a potential superior method to satisfy these requirements.

In supplying the electrical and thermal requirements of a facility, the most effective and economical use of fuel resources is accomplished by locating an efficient electrical generation system adjacent to the thermal energy load and fully utilizing the "waste" heat which is a by-product of any energy conversion process.

The potential of on-site energy systems has not yet been realized because available internal combustion power plants do not meet the performance and environmental requirements of typical sites. Noise and pollution from conventional equipment limits the number of sites at which the equipment can be located or leads to increased installation expense. The fuel cell is a primary candidate for solving these problems. The fuel-to-electrical conversion process is electrochemical and involves no moving parts or high temperatures. The fuel cell's efficiency is the highest of any available on-site system at full or part load. Exhaust emissions are orders of magnitude lower than present Environmental Protection Agency standards. The power plant is very quiet, producing noise levels equivalent to residential background levels.

Currently the Department of Energy (DOE), the Gas Research Institute and member gas utilities, are funding an operational fuel cell field test program through the United Technologies Corporation (UTC). The 40-kW On-Site Fuel Cell Operational Feasibility Program will result in the evaluation of up to 49 UTC 40-kW fuel cell power plants through the United States and Japan.

The Department of Defense, in cooperation with DOE, is funding the procurement and field testing of four additional 40-kW power plants. One of these power plants is to be tested at Sheppard AFB, Texas. Operation of this unit will provide a basis for evaluating the potential of this new energy technology at other Air Force installations. It is believed that some utilities participating in the field test program are also interested in testing fuel cells on Air Force installations which they service. This study is directed, in part, at locating these test sites. It will also aid in improving the understanding of the operational and economic benefit potential of on-site fuel cell energy systems in military facilities. To accomplish these objectives application analyses were conducted on selected sites at three designated Air Force Logistic Command Bases. These bases included:

- Wright-Patterson Air Force Base, Ohio
- Hill Air Force Base, Utah
- Robins Air Force Base, Georgia

FUEL CELL POWER PLANT CHARACTERISTICS

As shown in Figure 2-1 on-site fuel cell power plants have been under development at UTC for roughly twenty years. The present 40 kilowatt power plant was developed subsequent to a national field test of 12.5-kW units at 35 sites, under the gas industry sponsored TARGET (Team to Advance Research in Gas Energy Transformation) Program. This work is continuing under Gas Research Institute (GRI) and Department of Energy (DOE) sponsorship.

In general, fuel cell power plants offer a unique combination of characteristics especially suited to on-site energy service. These include: negligible air pollution, high electrical efficiency, high potential for thermal recovery and quiet, vibration free operation, which increases siting opportunities. Because of these "good neighbor" features the primary emphasis on site selection generally concentrated on locating applications which would fully utilize the energy conservation capabilities of the fuel cell.

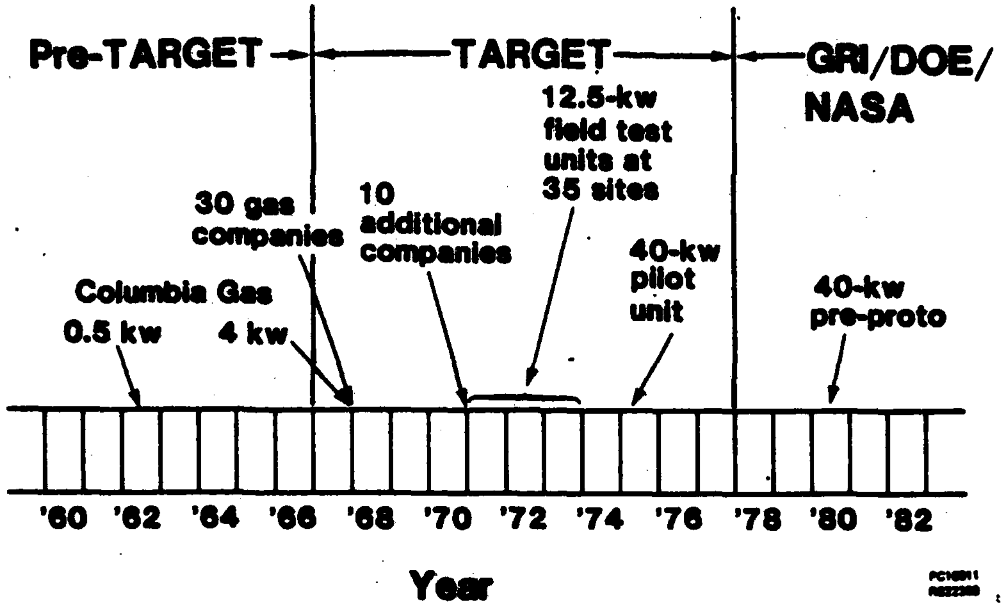


Figure 2-1. UTC On-Site Fuel Cell History

The 40 kilowatt power plant is designed for all weather and unattended operation. These features permit roof top or ground level, indoor or outdoor installation in many locations. The 40 kilowatt power plant is shown in Figure 2-2.

During operation the fuel cell will simultaneously generate up to 40-kW, 60 Hz electrical power and recoverable thermal energy. The fuel cell process is shown conceptually in Figure 2-3. The fuel cell process consists of:

- a chemical transformation of the fuel to hydrogen;
- an electrochemical conversion of hydrogen and oxygen (from air) to dc power; and,
- a power conditioning step where the dc power is converted to ac power.

Figure 2-2. The 40-kW Power Plant (WCN-9123)

Hydrocarbon fuel to electric power

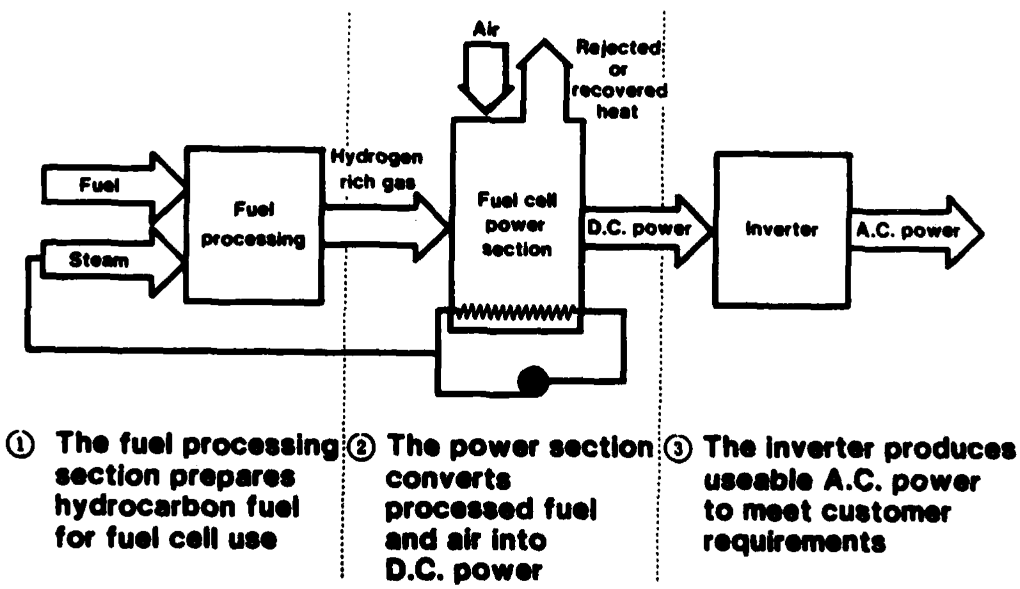


Figure 2-3. Major Fuel Cell Subsystems

Heat generated by the conversion process must be removed from the system. This heat can be rejected to air or water or recovered for cogeneration applications. The fuel source is pipeline natural gas or peak shaved gas. The power plant may be connected in parallel with the electric utility grid or it may be operated isolated from the grid. When in grid connected operation the power plant may be automatically switched to handle an isolated critical load should there be an interruption in normal utility service.

Two sources of recoverable heat in the form of hot water are available from the power plant. These sources are illustrated in the system schematic in Figure 2-4. A high grade supply is available at temperatures up to 275°F and represents roughly one-third of the total recoverable heat at full power output. Delivery of high grade heat to the thermal load is controlled by the power plant and is only delivered as it becomes available from an internal cooling system. A 3-way valve in the power plant bypasses the high grade heat exchanger when high grade heat is not available. During bypass the exit temperature roughly equals the inlet temperature. High grade heat is available from one-half to full power as shown in Figure 2-5.

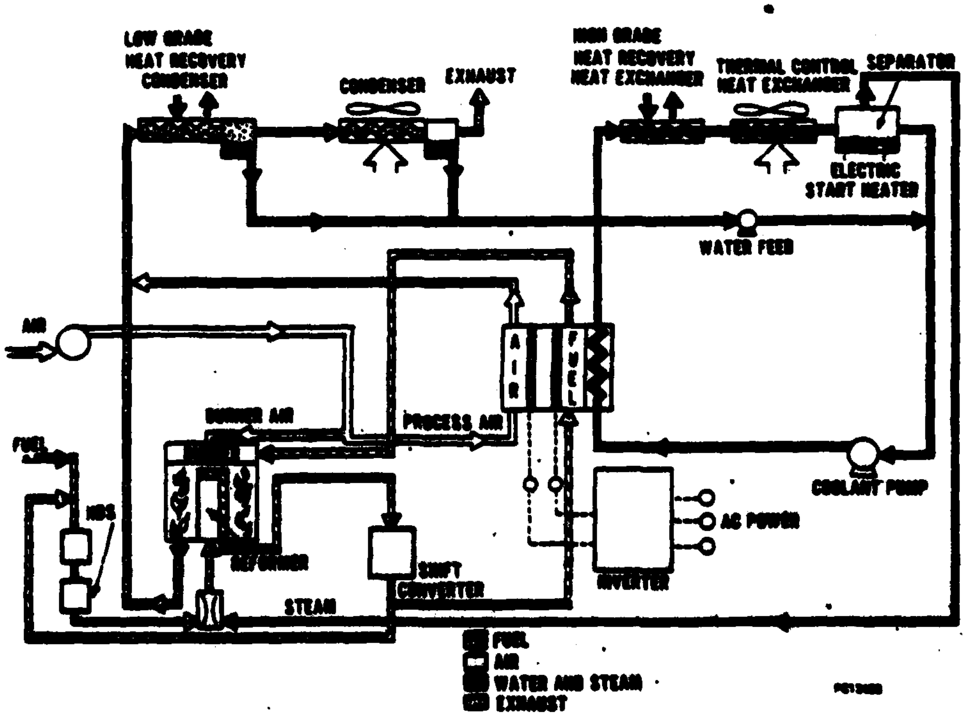


Figure 2-4. 40-kW Power Plant System Schematic

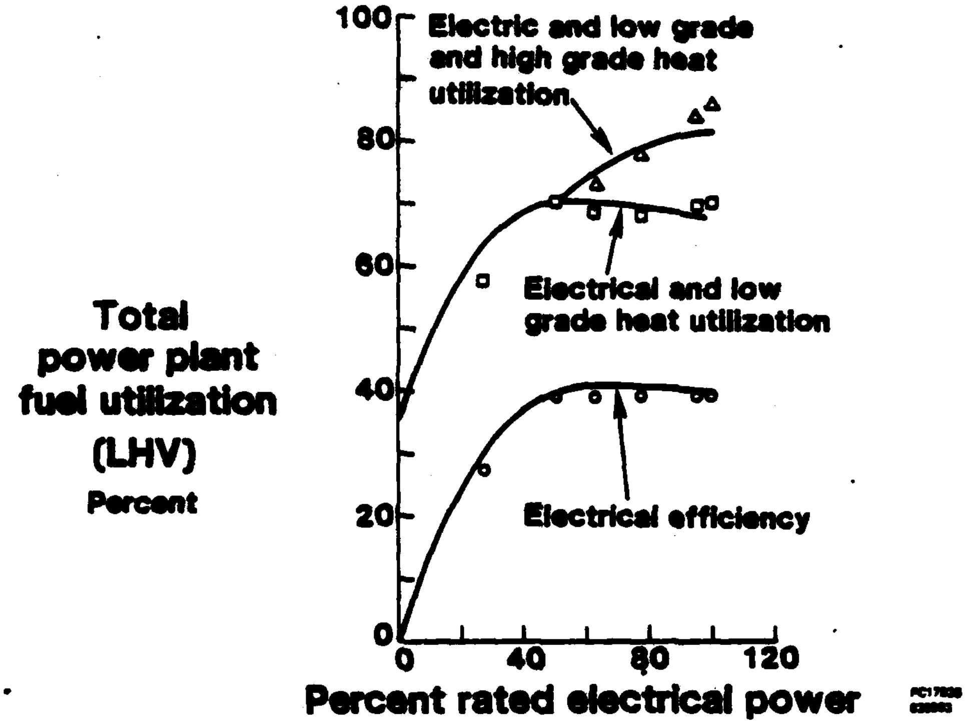


Figure 2-5. 40-kW Power Plant Performance

Low grade heat is also available from the power plant. Assuming return inlet temperatures to the power plant of 80°F, in full power operation 100,000 Btu/Hr of low grade heat is available at a supply temperature of 160°F. The fraction of this heat that can be recovered and the supply temperature is controlled by the customer supplied return temperature and flow rate to the power plant.

TYPICAL FUEL CELL SYSTEM CONFIGURATION

The most favorable Air Force applications are those in which maximum advantage is taken in the utilization of the fuel cell's electrical and thermal energy.

Since the installed power plant capacity is generally small relative to the base electric requirements, the power plant is normally operated at full power in a grid connected configuration. Sizing for a nearly continuous thermal load insures full use of the recoverable heat operating at full power. Electricity generated in

excess of the building requirements is used within the base and contributes to a reduction in purchased electricity. Conventional utility service satisfies building electrical needs during power plant maintenance.

Because the fuel cell automatically switches to isolated operation in the event of a conventional utility power outage, additional benefits are derived by having the fuel cell power critical electric loads. The high and low grade heat sources are independent systems and can handle independent loads. In applications where large hot water or process loads exist both heat sources are linked in series to simplify the installation and still make full use of fuel cell heat. Makeup water is first passed through the low grade heat exchanger. Heat delivered in this heat exchanger is a strong function of supply temperature. Makeup water supplied at cool ground temperature levels maximizes the heat delivered. Flow from the low grade source is directly fed to the high grade heat exchanger. High grade heat delivery is not a strong function of supply temperature and thus will deliver all of the heat available at the operating power levels. An example of this system is shown in Figure 2-6. In the event that the application thermal requirement is discontinuous a thermal storage device may be employed. This system is shown in Figure 2-7. The makeup water is plumbed such that it first passes through the low grade heat exchanger. This configuration insures maximum heat delivery by keeping the heat recovery system supply temperature to the fuel cell as low as possible.

Depending upon the application requirements a number of other system configurations are possible. Figure 2-8 illustrates an application with both a domestic hot water and a process heat requirement. The requirements are supplied independently by the fuel cell. The constant temperature bath is a good application of the high grade supply.

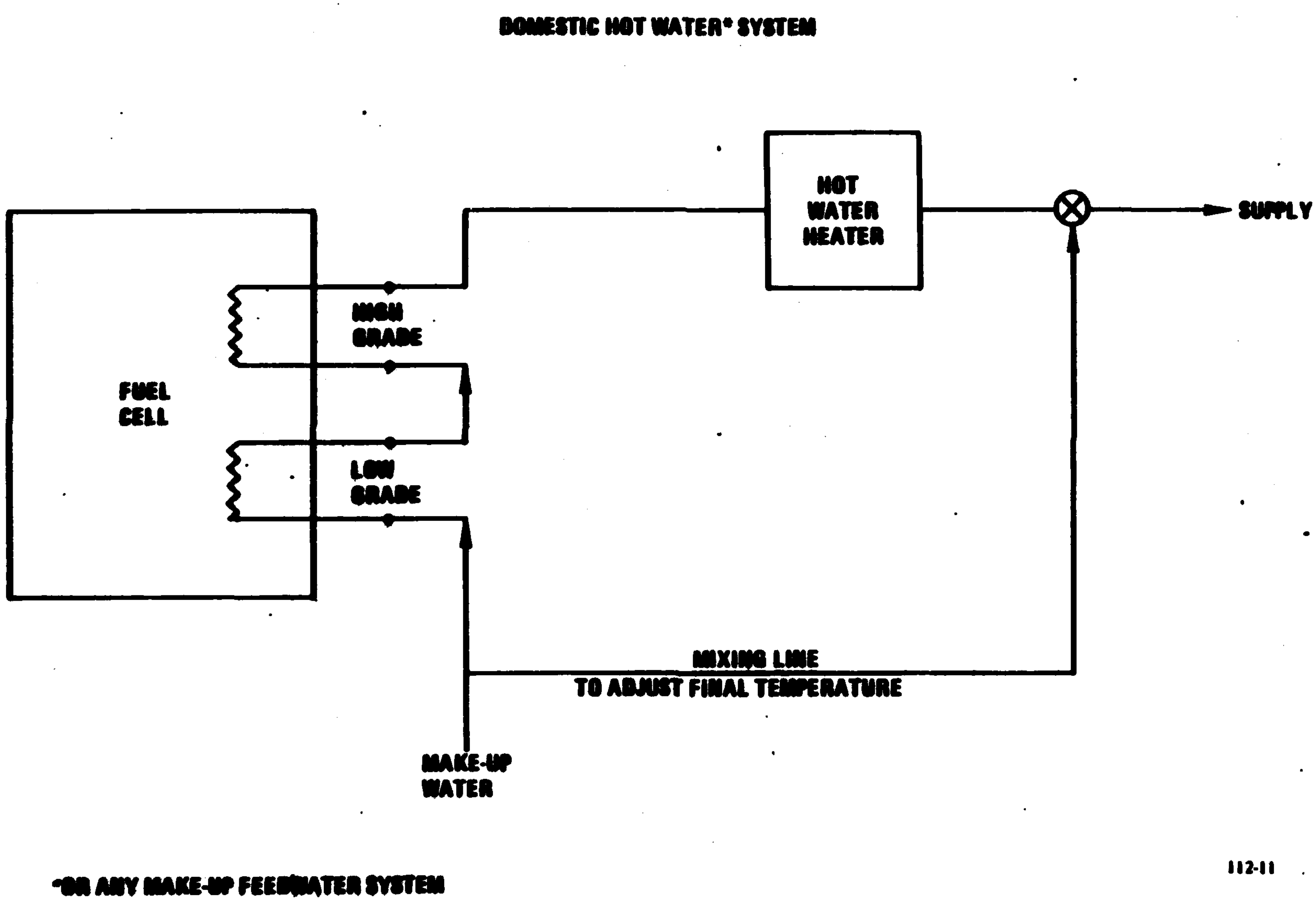
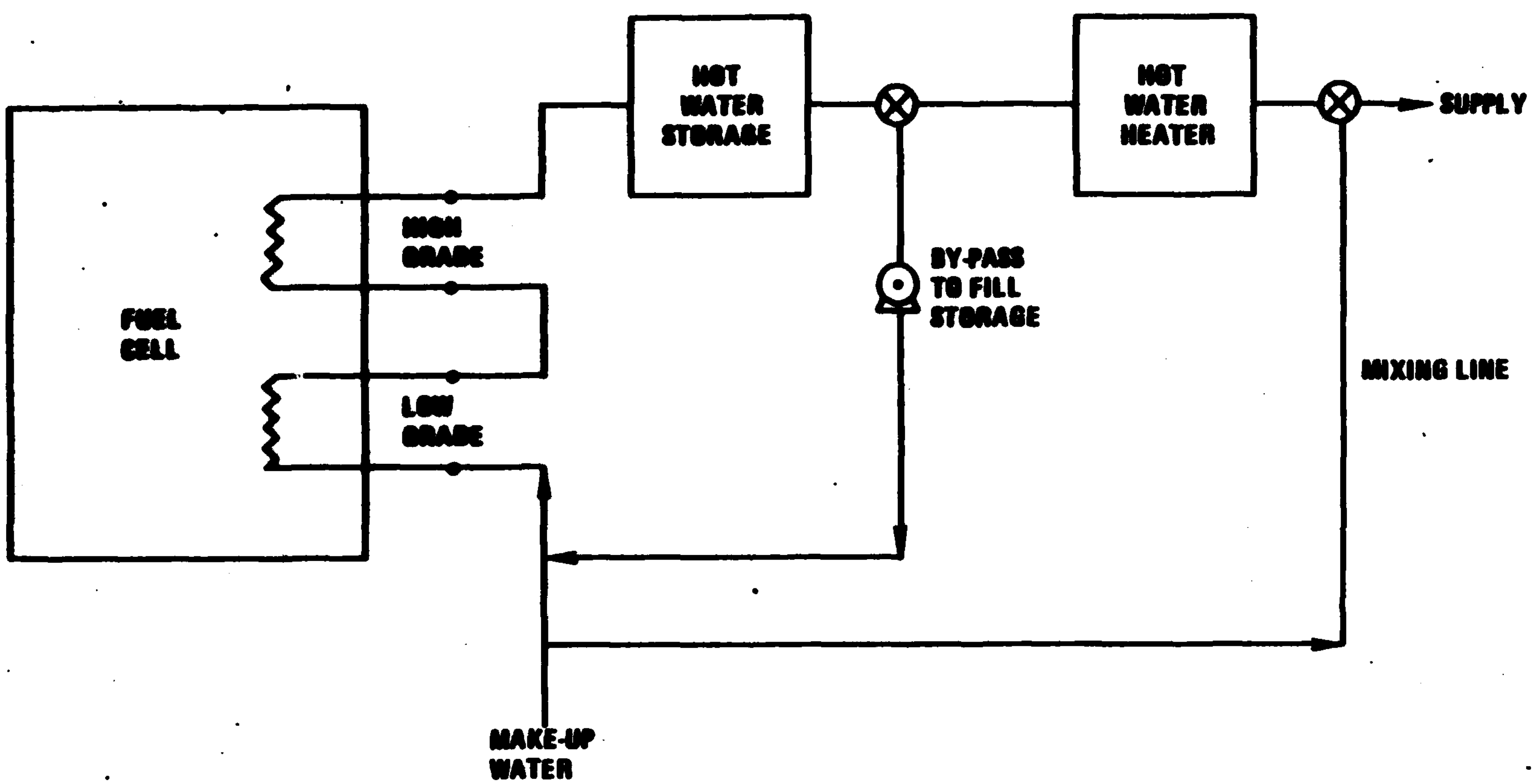


Figure 2-6. Typical Fuel Cell Thermal Interface with a Domestic Hot Water System

DOMESTIC HOT WATER* SYSTEM WITH THERMAL STORAGE



*OR ANY MAKE-UP FEEDWATER SYSTEM

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Figure 2-7. Typical Fuel Cell Thermal Interface with Storage Interfaced with a Domestic Hot Water System

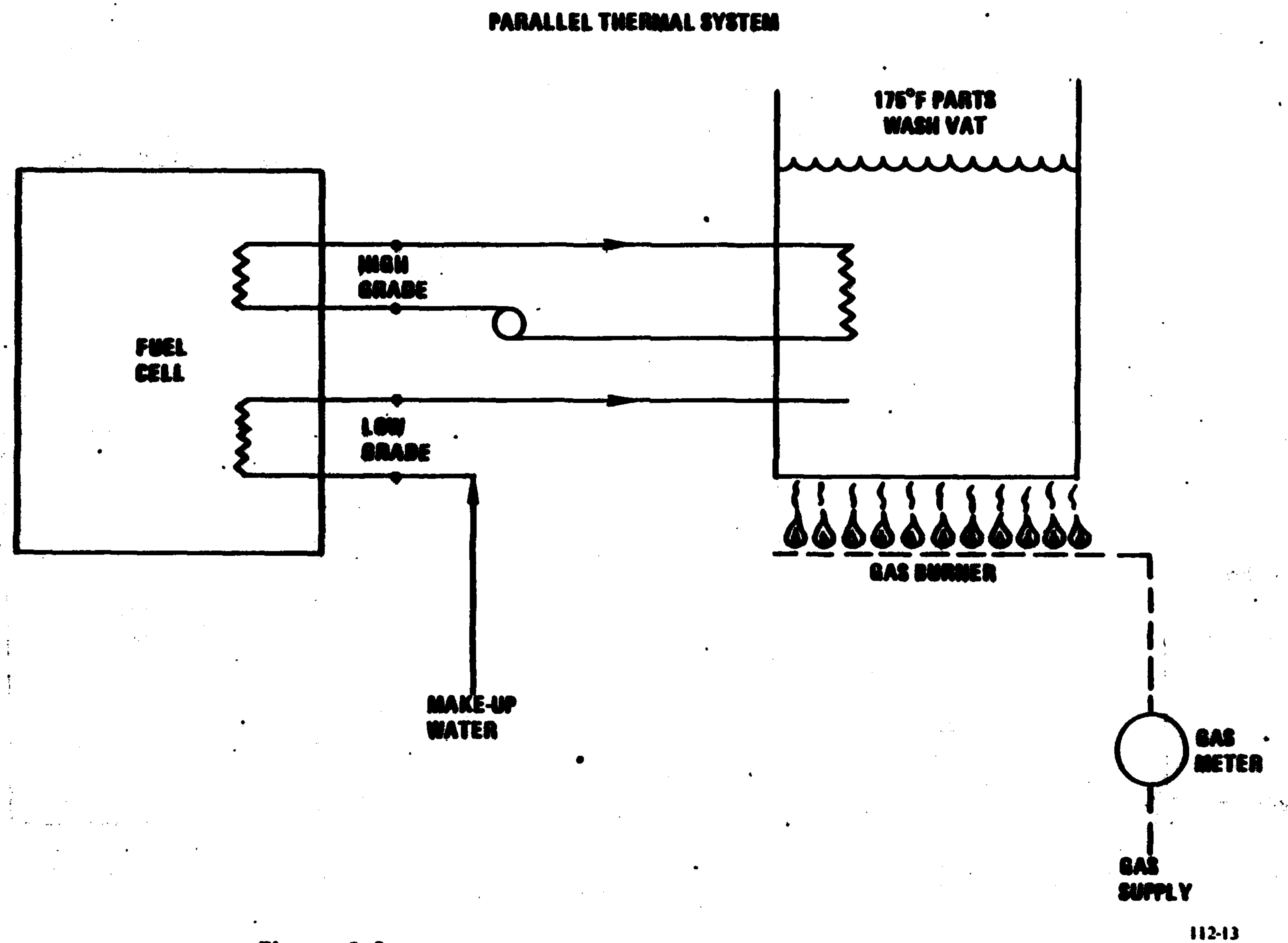

Figure 2-8. Example Fuel Cell Thermal Interface with Independent Loads

Section 3
SITE SELECTION PROCESS

APPROACH

The initial objective of this study was to identify potential 40-kW on-site fuel cell energy system test sites at selected Air Force Logistics Command Bases. The selection of these test sites was guided by an overall set of criteria. The selection process proceeded in two phases as shown in Figure 3-1. In the first phase, the AFLC bases selected from among its facilities those sites which they felt best met the site selection criteria. It was recommended that a minimum of five sites be submitted.

To assist with their selections each Air Force Logistics Command Base was given background information which described:

(a) program objectives,
(b) fuel cell power plant characteristics,
(c) typical fuel cell system configurations, and
(d) Air Force site selection criteria.

Also provided was a 40-kW fuel cell specification (reference 1) and a data request form to be completed and submitted for each site selected. To compliment the survey form data, a one-line diagram or sketch of the present thermal system and a second diagram illustrating a proposed fuel cell integration were requested. A copy of this material is included as Appendix B.

In the second phase UTC analyzed the technical data to estimate the potential conservation and economic benefits of an on-site fuel cell system at each site. For the analysis UTC utilized application analysis computer programs developed in conjunction with the nationwide fuel cell test program now underway. Based on the results of this analysis, and in conjunction with the site selection criteria and direction from the Air Force Project Officer, UTC selected individual sites for further analysis. For each of these sites UTC recommended a conceptual design

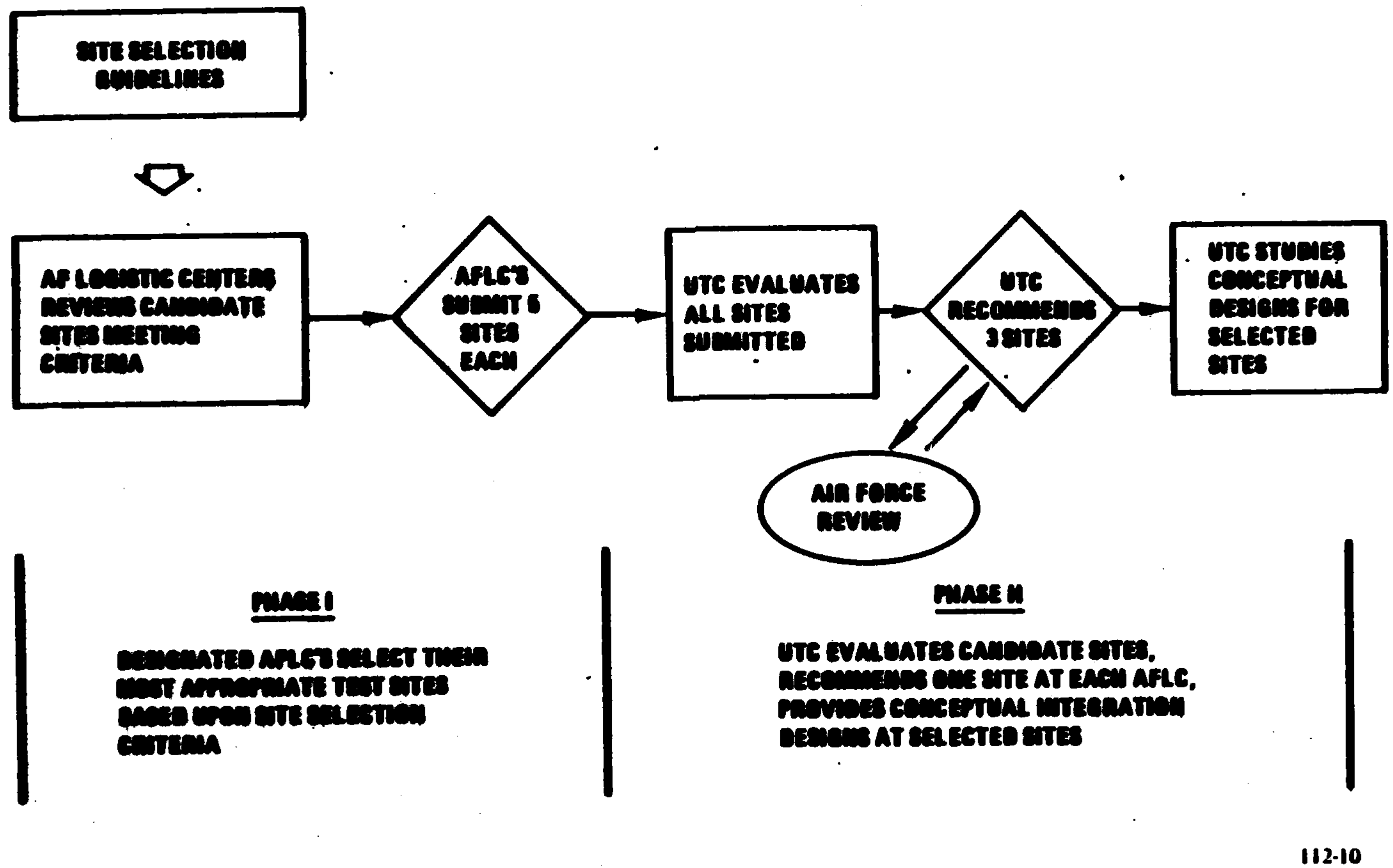

Figure 3-1. Application Analysis Flow Chart

integrating the 40-kW system with the existing facility energy system. Facility modifications and installation methods which would maximize the utilization of the fuel cell power plants' electrical and thermal output were also described as appropriate.

SITE SELECTION CRITERIA

With the direction of the Air Force Project Officer the following site selection criteria were developed for use by the designated Air Force Logistics Command Bases.

- Site should be representative of a class or type of application common to the Air Force and commercial applications to help foster local utility interest in participation.
- Site should be suitable for display and demonstration to selected Air Force personnel and the public. Consideration should be given to aesthetics, safety and visitor facilities.
- The fuel cell site should be in a reasonable proximity to the site thermal load. Thermal load should be temperature compatible and as nearly continuous as possible (requirement of approximately 150,000 Btu per hour or nearly 110 million Btu per month). Thermal storage may be utilized to improve coincidence.
- It would be desirable if the application has a critical load requirement for backup emergency power of less than 40 kilowatts.
- The voltage and other electrical interface requirements should be compatible with power plant specification.
- A natural gas supply should be near the site.

Section 4
FACILITY APPLICATION ANALYSIS

BUILDING CHARACTERISTICS

The three designated Air Force Logistic Command Bases submitted a total of thirteen potential fuel cell test sites. Wright-Patterson AFB submitted 9 sites with Hill and Robins AFB's submitting 3 and 1 site(s), respectively. Overall, the thirteen sites represent a diversity of applications. The facilities submitted are listed in Table 4-1 along with an estimate of their electrical power and energy requirements.

The overall accuracy of the fuel cell application analyses for these sites is directly influenced by the accuracy of the energy consumption records for these sites. Of the thirteen sites only two, the Air Force Museum (Building 489) and the steam plant (Building 644), had metered energy data. Metered data is noted in Table 4-1 by an asterisk. All of the other eneregy requirements were derived and represent the best estimates of the respective base personnel. In some cases, electric data were provided in the form of estimated kilowatt demand as a function of time of day. These data were scaled to derive estimated annual consumptions.

The thermal data for all facilities except the Air Force Museum (Building 489) and steam plant (Building 644) represented only a portion of the total thermal requirement of each facility. In these eleven buildings, the space heating requirements were not estimated. Since space heating requirements are seasonal, these loads would not be the optimum place to put the thermal output available from an on-site fuel cell energy system. As noted previously, highest fuel cell thermal utilizations can be achieved in those applications which require steady year round (non-seasonal) heating. This is especially true in those cases where fuel cell thermal output can be used for makeup water heating, as in the case of domestic hot water. Base personnel have generally attempted to match fuel cell heat with preheat or low temperature heating applications.

TABLE 4-1. AIR FORCE BASE FACILITY ENERGY REQUIREMENTS

Base (location)	Bldg. #	Use	ESTIMATED ANNUAL ENERGY USE Peak Demand (kW)	Electric $(10^3$ kWH$)/$YR	Thermal $(10^6$ Btu$)/$YR	Comments Regarding Reported Thermal Requirement
Wright-Patterson (Ohio)	262	Headquarters	4,500	16,000	1,700	Hot water only
	855	Officers quarters	300	750	3,400	Hot water only
	826	Officers quarters	275	700	3,100	Hot water only
	849	Gymnasium	60	350	2,400	Hot water/ pool heating
	489	Museum	1,855*	6,000*	0	All electric
	1240	Heating plant	1,600	12,000	2,600	Feedwater only
	127	Cafeteria	100	250	1,000	Hot water only
	1214	Dining hall	100	300	2,300	Hot water only
	830	Medical center	1,800	6,450	15,500	Hot water only
Hill (Utah)	521	Airmen dorm	97	237	1,600	Hot water only
	570	Hospital	183	675	4,700	Hot water only
	505	Plating shop	1,080	7,638	204,000	Process heating
Robins (Georgia)	644	Steam plant	293	695*	241,800*	Steam & hot water

* Actual use (metered loads)

In viewing the existing annual thermal use column in Table 4-1 we would note that many of the applications show good potential to fully utilize heat from the fuel cell. One 40-kW fuel cell operating continuously at full power produces roughly 1320 million Btu per year or the equivalent output from a conventional boiler of 2000 million Btu per year. In the case of the medical center (Building 830) there is sufficient load to support multiple fuel cell units. The same is true of the electroplating shop (Building 505). The thermal output from one 40-kW fuel cell is also small compared to the requirements of the steam plant (Building 644). In this application available fuel cell high grade thermal would be temperature compatible with all of the plant heating requirements including both feedwater and steam heating. Fuel cell low grade thermal would be compatible with the makeup feedwater requirement.

The Air Force Museum is currently an all electric facility. Energy data supplied for this facility included total monthly kilowatt-hour consumption and associated peak electric demand. There is no separate metering to define the component electric requirements associated with (a) space heating, (b) air conditioning, (c) ventilation, (d) lighting, and (e) domestic hot water consumptions. The domestic hot water load for this facility is negligible. An estimated breakdown of the other component electric loads was derived from the total monthly electric consumption, the summer peak electric demand, the estimate peak air conditioning demand and the monthly space heating degree-day requirement. The resulting component electric profile is shown in Figure 4-1. The intended use for fuel cell heat in this facility would be to displace a portion of the electric space heating requirement. Since the domestic hot water requirement is negligible there would be no significant use of fuel cell heat during the summer.

FUEL CELL APPLICATIONS ANALYSIS

All data submitted were coded for computer analysis using the "Building Analysis Survey Program" developed by UTC in conjunction with the gas utility sponsored 40-kW field test program. In order to estimate the amount of building thermal requirement that one 40 kilowatt fuel cell power plant could displace, all thermal requirements were coded as equivalent gas consumption.

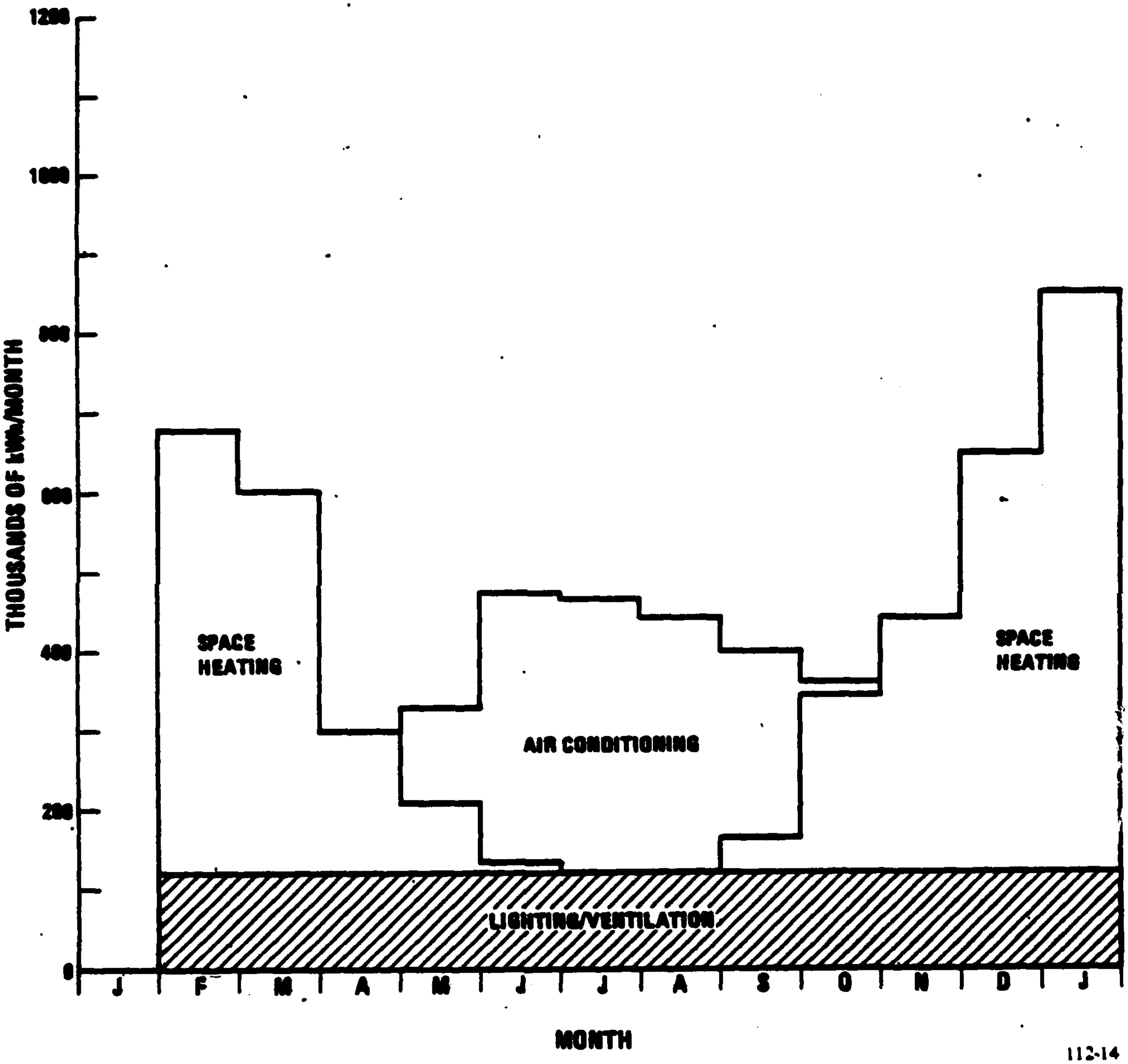

Figure 4-1. Air Force Museum Electrical Consumption

In the case of the Air Force Museum the estimated annual electric space heating load of 3.17 million kilowatt-hours was converted to an equivalent gas input of 16,645 million Btu assuming a seasonal average gas boiler efficiency of 65%. In making this adjustment, the peak demand of 1855-kW (winter peak) changes to an estimated 900-kW (summer peak) with the winter peak dropping to 375-kW. The adjusted winter peak primarily represents the lighting/ventilation requirement. A computer summary of this adjusted Air Force Museum data along with the other facility data is included in Appendix A, Table A-2 "BUILDING DATA SUMMARY". Appendix A, Table A-1 summarizes the definition of terms used and the options available for the analysis.

For this study each facility is analyzed assuming one 40-kW fuel cell installed on-site and operated continuously at full power. However, due to the large electric consumption in these facilities, all but three require supplemental electricity. For these cases of excess electricity, it was assumed that the excess would be consumed at other locations within the base thus further reducing the net purchase of electricity at the base. The results of the analysis are shown in Table 4-2. Fuel cell heat utilized ranged from a high of 89% in the Hill AFB electroplating shop (Building 505) and steam heating plant (Building 644) to a low of 38% in the Wright-Patterson AFB cafeteria (Building 127). It is anticipated that actual utilizations could be higher than the computer estimates since the intended thermal loads are fairly independent of seasonal variation.

Table 4-2 also presents operating savings which illustrate the expected annual dollar savings in facility energy costs attributable to the installation of one 40-kW fuel cell. The operating cost comparison accounts for all facility equivalent gas and electric consumption including that for the on-site fuel cell. Fuel cell capital equipment and maintenance costs are not included in the estimates. Conventional thermal energy costs at each facility were evaluated based on the costs associated with a gas fired boiler operating at 65% efficiency. These assumptions should not effect the relative ranking among the sites at each base.

The level of operating savings varies considerably from one base to another, however, within each base the relative savings between sites are quite comparable. This indicates that, while some facilities are marginally better than others, the argument to select one site over another depends to a large extent on the other site selection criteria. The level of operating savings varies considerably from one base to another. Since all of the facilities have good to excellent fuel cell heat utilizations, the differences in operating savings are due predominantly to the geographic effect on utility rates. The rates submitted for use in this study are listed in Appendix A, Table A-3.

TABLE 4-2. ON-SITE FUEL CELL ENERGY SYSTEM ANALYSIS RESULTS

Air Force Base	Building #	Building Use	Fuel Cell Heat Utilized	Operating Savings
Wright-Patterson	262	Headquarters	57%	$7,000/year
	825	Officers quarters	55	6,900
	826	Officers quarters	54	6,800
	849	Gymnasium	79	8,600
	489	Museum	70	8,000
	1240	Heating plant	49	6,400
	127	Cafeteria	38	5,600
	1214	Dining hall	61	7,300
	830	Hospital	61	7,300
Hill	521	Airmen dorm	50	13,700
	570	Hospital	75	14,800
	505	Plating shop	89	15,400
Robins	644	Steam plant	89	12,800

Section 5
SITE ANALYSIS

It is planned that the testing of 40-kW fuel cell power plants by the Air Force will be preceded by a period of facility data monitoring and evaluation. This step will insure that the final site or sites selected for testing are technically compatible with the 40-kW fuel cell power plant. In addition, the evaluation of continuously monitored energy demands in the buildings will accurately determine, prior to actual testing, the amount of power plant waste heat that can be utilized. This instrumentation step is an important element of the present nationwide test of 40-kW fuel cells by the gas utility industry. The gas utilities will instrument approximately three sites for every one selected for testing. Each instrumented site adds valuable data to the overall definition of the application requirements for on-site fuel cell power plants.

UTC's analysis and recommended sites for field testing is based upon the site selection criteria and the estimated utilization of fuel cell available heat. Table 5-1, 5-2 and 5-3 summarize information relating to the site selection criteria for each site.

TABLE 5-1. HILL AFB - SITE SELECTION CHARACTERISTICS

	CANDIDATE SITE CHARACTERISTICS		
	AIRMEN DORMITORY BLDG. #521 HILL AFB	HOSPITAL BLDG. #570 HILL AFB	ELECTROPLATE SHOP BLDG. #505 HILL AFB
SITE SELECTION CRITERIA			
• Site suitable for public display	*	*	*
• Representative of additional facilities throughout DOD	*	*	*
• Thermal - Utilization	Excellent	Excellent	Good (high grade)
- Requirement	Domestic hot water	Domestic hot water(1)	Process heating
- Distance to load	25'	200'	200'
• Electrical interface	Matches	Transformer required	36 kW dc/tank load specified
• Distance to fuel supply	500'	350'	In building
• Emergency power requirement	None	Existing 500-kW	Yes but no present backup

* Submitted by responding base as suitable to meet criteria

(1) Recommended by Hill AFB as a two 40-kW powerplant site

TABLE 5-2. ROBINS AFB - SITE SELECTION CHARACTERISTICS

SITE SELECTION CRITERIA	STEAM HEATING PLANT BLDG #644 ROBINS AFB
• Site suitable for public display	*
• Representative of additional facilities throughout DOD	*
• Thermal - Utilization	Excellent
- Requirement	Feedwater heating
- Distance to load	30'
• Electrical interface	Transformer Required
• Distance to fuel supply	Interruptible line 25' Non-interruptible line 150'
• Emergency power requirement	Existing 150-kW

* Submitted by responding base as suitable to meet criteria

TABLE 5-3. WRIGHT-PATTERSON - SITE SELECTION CHARACTERISTICS

	CANDIDATE SITE CHARACTERISTICS		
	AFLC HEADQUARTERS BLDG #262 WRIGHT-PATTERSON AFB	OFFICERS QUARTERS BLDG. #825 WRIGHT-PATTERSON AFB	OFFICERS QUARTERS BLDG. #826 WRIGHT-PATTERSON AFB
SITE SELECTION CRITERIA			
● Site suitable for public display	*	*	*
● Representative of additional facilities throughout DOD	*	*	*
● Thermal - Utilization	Excellent	Excellent	Excellent
- Requirement	Domestic hot water	Domestic hot water (1)	Domestic hot water
- Distance to load	50'	50'	50'
● Electrical interface	Yes - at one power distribution center	Matches	Matches
● Distance to fuel supply	In building	75'	200'
● Emergency power requirement	2 - 200-kW	None	None

* Submitted by responding base as suitable to meet criteria

(1) Option to use high grade fuel cell heat in existing steam/hydronic fan coil system

TABLE 5-3. WRIGHT-PATTERSON - SITE SELECTION CHARACTERISTICS (Cont'd)

	CANDIDATE SITE CHARACTERISTICS		
	OFFICERS GYMNASIUM BLDG. #849 WRIGHT-PATTERSON AFB	AIR FORCE MUSEUM BLDG. #489 WRIGHT-PATTERSON AFB	CENTRAL HEAT PLANT BLDG. #1240 WRIGHT-PATTERSON AFB
SITE SELECTION CRITERIA			
• Site suitable for public display	*	Excellent	*
• Representative of additional facilities throughout DOD	*	Yes (2)	*
• Thermal - Utilization	Excellent	Good	Good
- Requirement	(1)	Space Heat	Feedwater heating
- Distance to load	50'	50'	75'
• Electrical interface	Matches	Matches	Transformer may be required
• Distance to fuel supply	In building	2000' crossing a concrete runway	200'
• Emergency power requirement	None	2 units (5-kW) for emergency lighting	3 750-kW units

* Submitted by responding base as suitable to meet criteria

(1) Domestic hot water and swimming pool water heating
(2) Represents hangar class of facility

TABLE 5-3. WRIGHT-PATTERSON - SITE SELECTION CHARACTERISTICS (Cont'd)

	CANDIDATE SITE CHARACTERISTICS		
SITE SELECTION CRITERIA	CAFETERIA BLDG. #127 WRIGHT-PATTERSON AFB	AIRMEN'S DINING HALL BLDG. #1214 WRIGHT-PATTERSON AFB	BASE HOSPITAL BLDG. #830 WRIGHT-PATTERSON AFB
• Site suitable for public display	*	*	*
• Representative of additional facilities throughout DOD	*	*	*
• Thermal - Utilization	Fair	Excellent	Excellent
- Requirement	DHW & Dishwasher	DHW & Dishwasher	Domestic Hot Water
- Distance to load	NA	NA	NA
• Electrical interface	NA	NA	Matches
• Distance to fuel supply	In building	50'	In building
• Emergency power requirement	None	None	Two 250-kW, 150-kW, 100-kW

* Submitted by responding base as suitable to meet criteria

DHW Domestic hot water

NA Not available

HILL AFB

Hill AFB identified and submitted three sites for consideration. The represented sites included (1) an Airmen's Dormitory, (2) a Hospital, and (3) an Electroplating Shop. Site selection criteria information for these sites is summarized in Table 5-1. Based upon this data and the energy system analysis results in Table 4-2, the Airmens' Dormitory (Building #521) is recommended for data monitoring/ evaluation and possible fuel cell test. This facility has a separate building which houses all of the mechanical equipment. Domestic hot water is provided by two steam heated storage tanks supplying a recirculating hot water loop. Space heating and cooling in the dormitory is provided via fan coil units fed from a hydronic loop. During the summer chilled water is delivered from a steam driven absorption chiller. During the heating season hot water converted from steam is delivered at 132°F, returning at 120°F. These low temperatures are usually the result of the fan coil units being sized for the air conditioning load. With this system fuel cell thermal output can be simply integrated with either the domestic hot water system or the space heating system or both in combination.

The Base Hospital (Building #570) was recommended by Hill AFB as a two power plant site. With one 40-kW unit installed an estimated 75% of the fuel cell thermal would be utilized (Table 4-2). With two units the overall utilization is estimated to be 67%, still an excellent value. This site is already serviced by a 500 kW emergency generator which suggests that a larger number of fuel cells might be warranted. With additional fuel cell units at some point it may be desirable to interface with the space heat system to maintain good thermal utilizations. Space heat in this hospital is provided by steam heated central air handlers with hydronic reheat (180-200°F) coils. The least capital intensive method to add fuel cell heat for space heating would be to pass the main reheat coil return line to the fuel cell high grade supply. A second option would be to break into the air return system with a specially sized hydronic to air heat exchanger. The hydronic supply would be sized for an 80°F return temperature and would integrate with the low and high grade heat recovery heat exchangers in series. From a test point of view this

hospital also has a thermal interface constraint in that the fuel cell heat is separated from its point of use by 200 feet. Electrically, a matching transformer would also be required. This hospital would be our second choice site at Hill AFB.

The Electroplating Shop (Building #505) is a unique application with considerable future potential as a fuel cell market for a direct current power source. At this particular site the electroplating baths are heated directly with steam. Due to the nature of the thermal load the thermal requirement would have to be measured based upon the amount of steam consumed. This is a much more difficult requirement for a data acquisition system when compared with the hot water systems in the dormitory and hospital above. In addition, the electroplating tank requires a 140 to 160°F bath temperature which would limit the amount of low grade fuel cell heat utilized. A separate heating coil would also need to be purchased and installed in conjunction with a separate hydronic loop in order to add fuel cell heat to the tank. At least one chemical plating operation is being instrumented by the gas industry as part of their fuel cell test program. This data should be available to the Air Force from the Gas Research Institute.

ROBINS AFB

Robins AFB was "restricted in site selection due to limited natural gas distribution lines". Considering this and the other selection criteria one site, Steam Plant No. 4 (Building #644), was submitted for evaluation. The plant produces steam for space heating, steam for one 325 ton absorption chiller and hot water for approximately 32 buildings. This application has a feedwater heating requirement (Table 5-2) which is estimated to make excellent use of both low and high grade fuel cell heat. In actual operation the fuel cell heat utilization should exceed the 89% reported in Table 4-2. Steam Plant No. 4 (Building #644) is recommended for data monitoring/evaluation and possible fuel cell test.

WRIGHT-PATTERSON AFB

Wright-Patterson AFB submitted nine sites for analysis. Of the nine sites listed in Table 4-1 only the cafeteria (Building #127) exhibited a thermal use significantly below the 2000 million Btu per year equivalent furnace output from one 40-kW fuel cell power plant. Based on thermal utilization (Table 4-2) this site would be the only marginal test site. A brief summary of the site selection criteria characteristics for each of these sites is shown in Table 5-3. After discussion with the Air Force project Officer the Air Force Museum (Building #489) is the recommended site for data monitoring/evaluation and possible fuel cell testing. This decision was strongly influenced by the superb public display aspects of this site. The most notable obstacle appears to be that the required gas supply line is roughly 2000 feet away across a no longer used runway. Space conditioning in the indoor display areas is presently maintained with individual air handling units using electric coils for space heating and chilled water coils for cooling. The cooling coils are not used during space heating operations and the system is drained. During the winter heat recovered from a 40-kW fuel cell could be fed to the cooling coil of one air handling unit via a separate hydronic loop. The existing electric coil, located downstream of the cooling coil, would be used to supplement the heat delivered from the fuel cell. The cooling coil should have more than sufficient capacity in a heating configuration to deliver all of the recoverable heat from one 40-kW power plant. The domestic hot water load is negligible. There would be no significant use of waste heat during the summer. It is recommended that the alternate site be chosen from the following prioritized group of facilities: (1) Officer's Gymnasium (Building #849), (2) Airmen's Dining Hall (Building #1214) and (3) Medical Center (Building #830).

The Officer's Gymnasium, a well landscaped brick building has a continuous summer and winter requirement for domestic hot water and for heating a 3000 square foot swimming pool. Both requirements would provide excellent use (79% utilization, Table 4-2) of both low and high grade fuel cell heat. The Airmen's Dining

Hall serves 1000 meals per day including breakfast, lunch and dinner. The building is a fairly well landscaped and constructed of cement blocks. Fuel cell heat utilization would also be excellent (61%) and would provide primary heating for domestic hot water (140°F) and dishwasher water (180°F) heating. The Gymnasium and Dining Hall do not have a significant emergency generation requirement. The Base Hospital contains 400 patient beds alone with a dental facility and a cafeteria. The cafeteria prepares 1300 meals per day. The building is concrete and well landscaped. The equipment room is in excellent condition. Fuel cell heat in this facility would be used for domestic hot water (140°F) for kitchen, dental and general hospital use. The computer analysis estimate of 61% fuel cell heat utilized (Table 4-2) is felt to be conservative. This facility has in place emergency generation covering 750-kW. The Base Hospital, however, is scheduled for major alterations over the next few years. These alterations will affect and interrupt hot water usage, site conditions, etc. which may preclude it from being a viable test site.

Section 6

CONCEPTUAL INTEGRATION DESIGNS

THERMAL SYSTEMS

An effective fuel cell thermal system configuration in each of the three recommended primary sites will depend upon measured energy consumption patterns in the major energy subsystems. Energy data monitoring and evaluation should play an important role in determining the most cost effective configuration. At this stage in the Air Force site selection process baseline conceptual thermal integration designs will be useful in helping to focus the data monitoring activity to those energy subsystems most likely to benefit from integration with the 40-kW fuel cell power plant. Subsequent evaluation of these energy use patterns will dictate the final configuration. It is anticipated that as Air Force knowledge of facility energy use develops, standard energy use patterns will be defined. At this time the requirement for pre-installation energy monitoring will lessen and off-the-shelf standardized fuel cell systems may be installed.

HILL AFB AIRMEN DORMITORY (BLDG. #521)

In this facility both the domestic hot water and space heating systems are candidates to integrate with by-product heat from a 40-kW fuel cell power plant. All of the equipment which satisfies the energy requirements of this building is contained in a separate adjacent mechanical equipment building. Domestic hot water is provided via two steam fired storage tank heaters (Figure 6-1). The tanks are each of 740 gallons capacity with a firing rate of 700,000 Btu/hr. These heaters are considered to be oversized by the base personnel. The domestic hot water system recirculates so that hot water is immediately available at each of the building fixtures. The Air Force estimates that monthly hot water consumption is 101,000 gallons/month. The average heating requirement is roughly 117,000 Btu/hour for a 100°F temperature rise. This ignores surface convection and radiation heat losses from the recirculating loop. It is assumed that one 40-kW fuel cell at this site would operate continuously at full power which would result in roughly 150,000

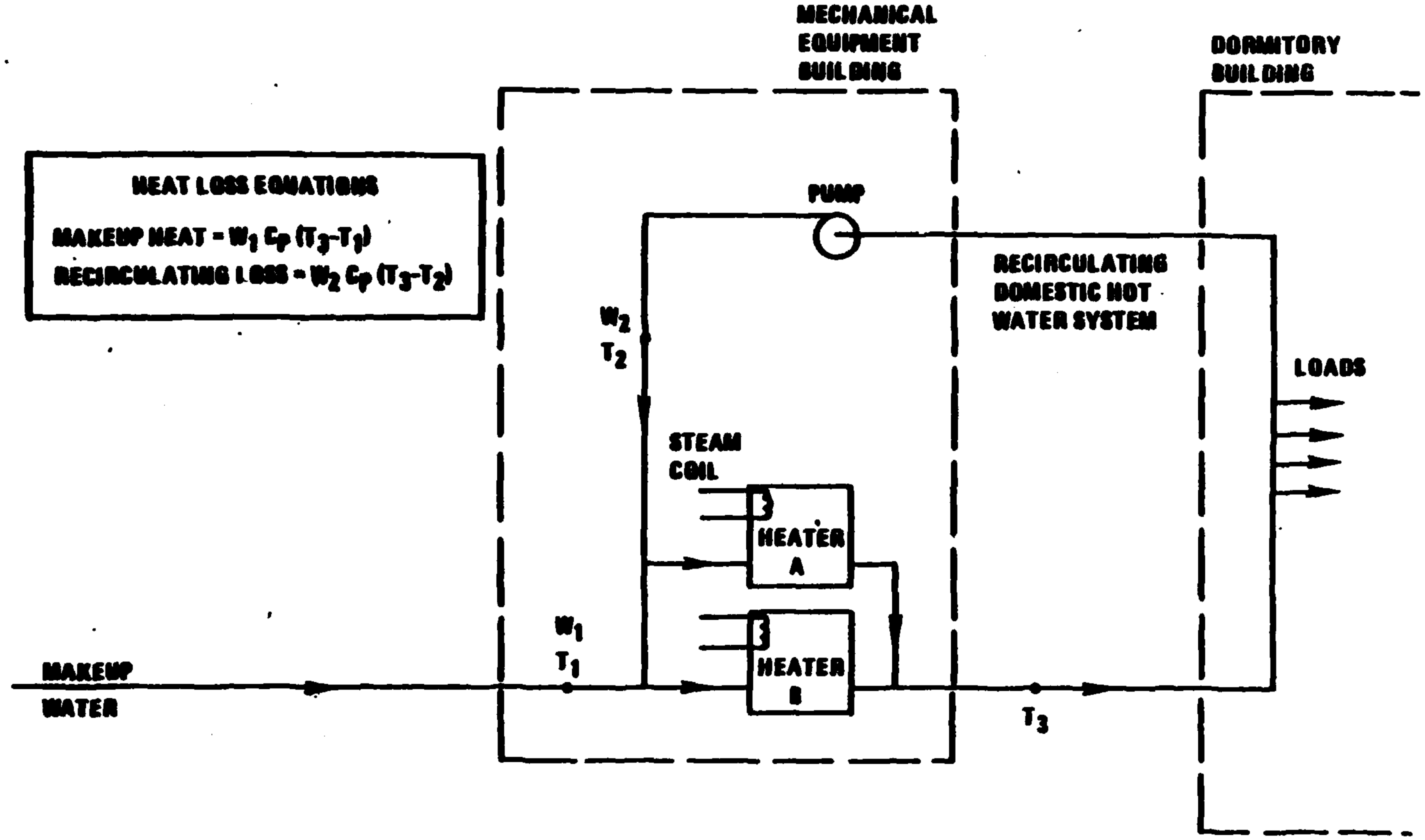

Figure 6-1. Existing Domestic Hot Water System Airmen's Dormitory (Bldg. No. 521), Hill AFB

Btu/hour of available heat. Given these estimates the fuel cell should satisfy all of the domestic hot water requirements.

As previously mentioned, data monitoring will ultimately dictate the best fuel cell on-site energy system configuration at this site. This domestic hot water system has two heating loads. The primary load is the makeup hot water load defined by W_1 Cp (T_3-T_1) on Figure 6-1. A secondary load also exists as a result of convection/radiation losses from the recirculating loop. The magnitude of this loss is controlled by the piping insulation levels and may or may not be significant. This loss is defined by W_2 Cp (T_3-T_2). It is recommended that data logger equipment have the capability to calculate these loads on a short term basis (as every 10 seconds) and accumulate the result for hourly data evaluations. The conceptual integration design for the dormitory domestic hot water system is shown in Figure 6-2. Makeup water would be directly preheated by passing through the fuel cell thermal recovery system heat exchangers. In the event of occasional high demand flow rates, nominal supply pressure (P) could be maintained by partial by-pass of both heat exchangers at valve V_1. Low grade heat is interfaced with the makeup water since the heat available from this source increases with decreasing inlet temperatures. For example, at full power design conditions 105,000 Btu/hr is available with an 80°F inlet. Available heat increases to 135,000 Btu/hr with a 40°F inlet temperature.

High grade heat is not significantly affected by inlet water temperature but is a strong function of electrical power output. With this dormitory system we would also recommend interfacing the high grade supply with the return from the recirculation loop. Interfaced this way the high grade supply should provide additional makeup water heating plus the stray heat losses associated with the recirculating hot water loop. To insure that the recirculating loop is not overheated the recirculating flow to the fuel cell can be modulated by a temperature controlled valve V_2.

An alternate conceptual integration design makes use of one of the existing heaters dedicated for use as a thermal storage tank. The merit of this optional concept

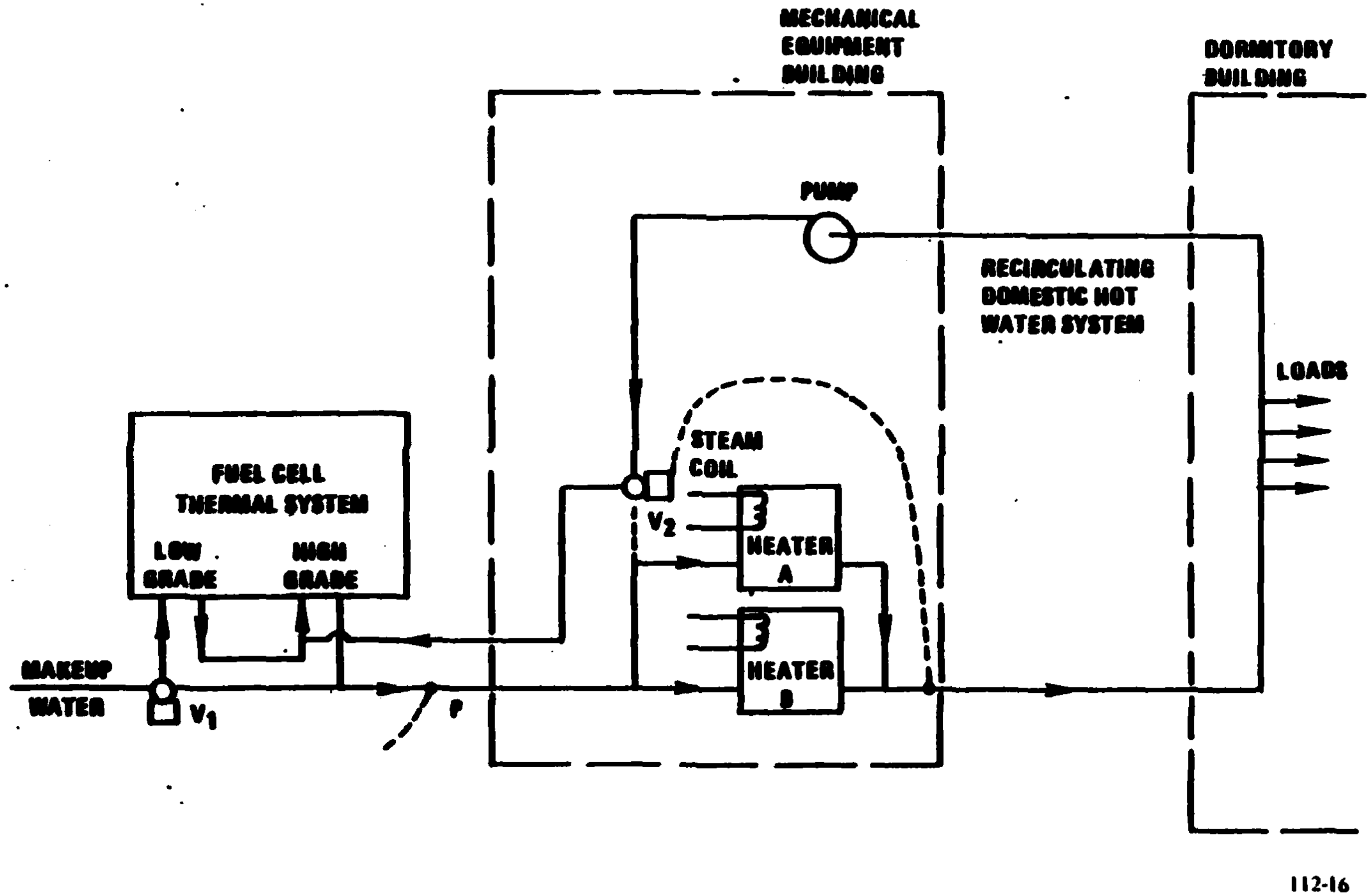

Figure 6-2. Conceptual Integration Design Airmen's Dormitory (Bldg. No. 521), Hill AFB

relative to the baseline concept would depend upon an evaluation of the instrumented energy requirements. Since there was an indication that the existing domestic hot water heaters were oversized, it is quite likely that the addition of fuel cell heat will eliminate the need for one of the heaters. This heater could be reconfigured and dedicated as a thermal storage tank with no supplemental heating capability. Integrating this with the fuel cell as shown in Figure 6-3 would permit the storage of fuel cell heat during low hot water demand periods. Storage would be controlled via the tank temperature (T) using pump P_2.

The electric peak demand at this site is not known but is estimated to be 97-kW based on information ratioed from data available from a Wright-Patterson AFB dormitory. Locating two power plants at this site would make available 3000,000 Btu/hour at design conditions. The additional heat could be used to reduce the space heating load. Space heating is provided in the dormitory with hydronic fan coil units. The hydronic loop is heated from steam (capacity 725,000 Btu/hour) and distributed at 132°F with a return temperature of 120°F. This space heating system should be ideally configured to integrate with the fuel cell thermal system in a situation in which a multiple power plant installation is warranted.

ROBINS AFB STEAM PLANT NO. 4 (BLDG. #644)

This facility operates twenty four hours per day year round. The facility produces steam for space heating and hot water for approximately 32 buildings. In the summer steam is also produced to drive a 325 ton absorption chiller. The facility also houses two large (200 HP, 74 HP) air compressors which produce compressed air for in-plant and adjacent building use. Steam is produced year round from interruptible natural gas. Oil is occasionally used during the winter months to supplement the natural gas.supply. A 150-kW diesel generator is used for emergency service.

Electricity for operating the controls, pumps, blowers, etc. in the plant was metered at 695,000 kWh from October 1980 thru September 1981. This is almost

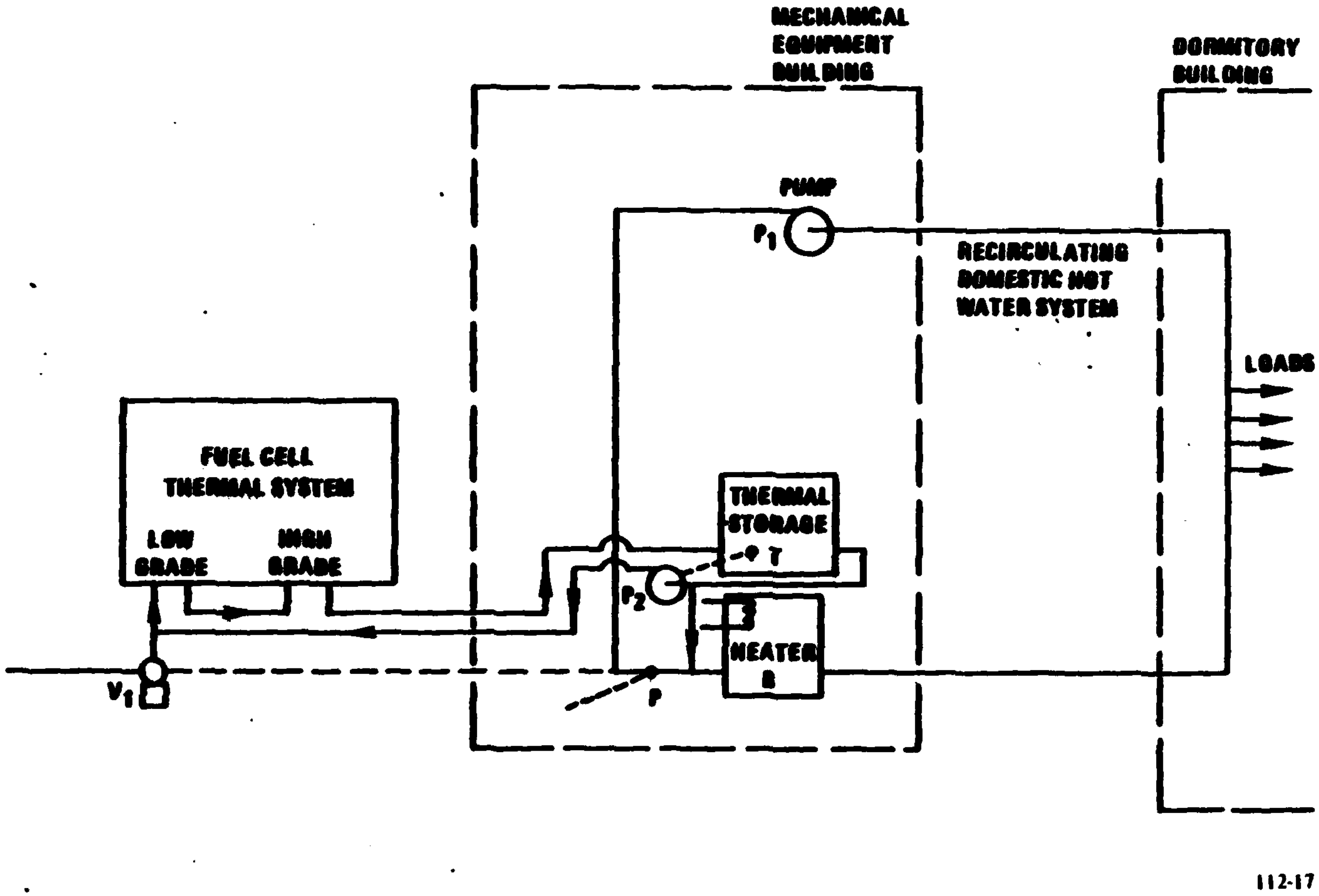

Figure 6-3. Alternate Conceptual Integration Design - Airmen's Dormitory (Bldg. No. 521), Hill AFB

exactly one-half the electrical output from one 40-kW fuel cell operated continuously at full power for one year. The peak demand in this site was not known but the connected load represents 391 HP or roughly 293-kW. Excluding the air compressors the connected load would be 85-kW.

The recommended use for fuel cell recovered heat in steam plant No. 4 would be for makeup feedwater heating. This feedwater requirement is not known but can be approximated based upon the metered fuel consumption at the site. Metered natural gas plus oil consumption accounted for approximately 242 billion Btu during one year. If we assume that the plant produces 110 psig steam at 70% efficiency with a condensate, return of 160°F and a makeup ground water temperature of 60°F, the feedwater heating requirement would be estimated to average 360,000 Btu/hr. This is slightly more than the thermal output of two 40-kW fuel cell units. The heat duty for feedwater heating plus condensate preheating is estimated at 1.5 million Btu per hour (average). Hence this facility would fully utilize the electrical and thermal outputs of a multi-power plant installation.

The integrated conceptual design at Steam Plant No. 4 is shown in Figure 6-4. Makeup feedwater is supplied from a well to a double tank storage system. Although the feedwater flow rate will vary it is assumed that the minimum flow requirements are still above the design flow (150 gph) through the 40-kW fuel cell thermal recovery system. Data monitoring at this site should include the feedwater flow, ground water temperature, condensate return temperature, condensate flow, and condensate preheater supply temperature as a function of time.

WRIGHT-PATTERSON AFB AIR FORCE MUSEUM (BLDG. #489)

Environmental control of the indoor display areas at this site is handled by eleven individual air handling units. Each air handling unit contains an electric driven blower, an electric coil for space heating and a chilled water coil for air conditioning. Chilled water is delivered to each air handling unit thru a hydronic loop from two central chillers. This hydronic loop is drained at the time of switch over to the space heating mode. The blowers run continuously during either heating or

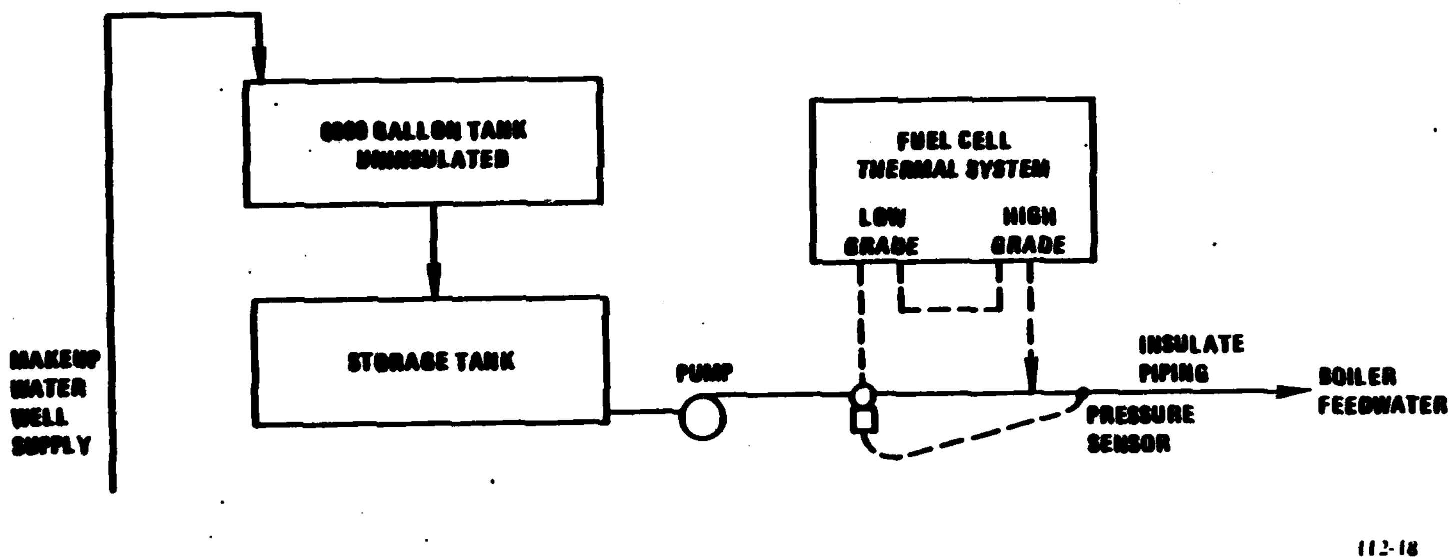

Figure 6-4. Conceptual Integration Design - Steam Plant No. 4 (Bldg. No. 644), Robins AFB

cooling operation. Electric coil capacities range from 65 to 175-kW (220,000 to 600,000 Btu/hr). A typical arrangement of this system is shown in Figure 6-5.

Due to the small temperature differentials associated with chilled water coils, these same are ideally suited for low temperature hydronic space heating. Since these coils are inoperative during the space heating season they can be adapted for delivering heat recovered from the fuel cell. Based upon the range of electric coil capacities, the fuel cell could be installed to interface with any one of the air handling units. The conceptual integration design for this system is shown in Figure 6-6.

The electric space heating coil is located in the blower air path downstream of the cooling coil. In this location the electric coil is ideally situated to act as a supplemental heater. Valves added to the supply and return lines of the coil (if they don't already exist) will isolate the coil from the main building chilled water lines. A separate hydronic loop would be added to transfer heat from the fuel cell to the coil. A circulating pump in this line would operate when the air handling unit thermostat calls for heat. During those periods when space heating is not required the fuel cells integral heat rejection system will automatically dump this heat overboard.

A hydronic thermal storage system could be evaluated during a data monitoring/ evalution program. It could be most cost effective to use the building itself for thermal storage. During those conditions when the building space conditioning thermostats are on night-time set back for energy conservation, the fuel cell thermal system could be controlled to continue to dump heat to the conditioned space. Since the electrical output of the fuel cell can be utilized at all times within the base, it is assumed that it would run continuously at full power. This approach would therefore utilize the heat capacity of the building and its contents to store the cogenerated heat available at all times from the fuel cell.

Data monitoring at this site should be straight forward since the space heating is provided with electrical resistance heaters. Kilowatt-hour consumption of the

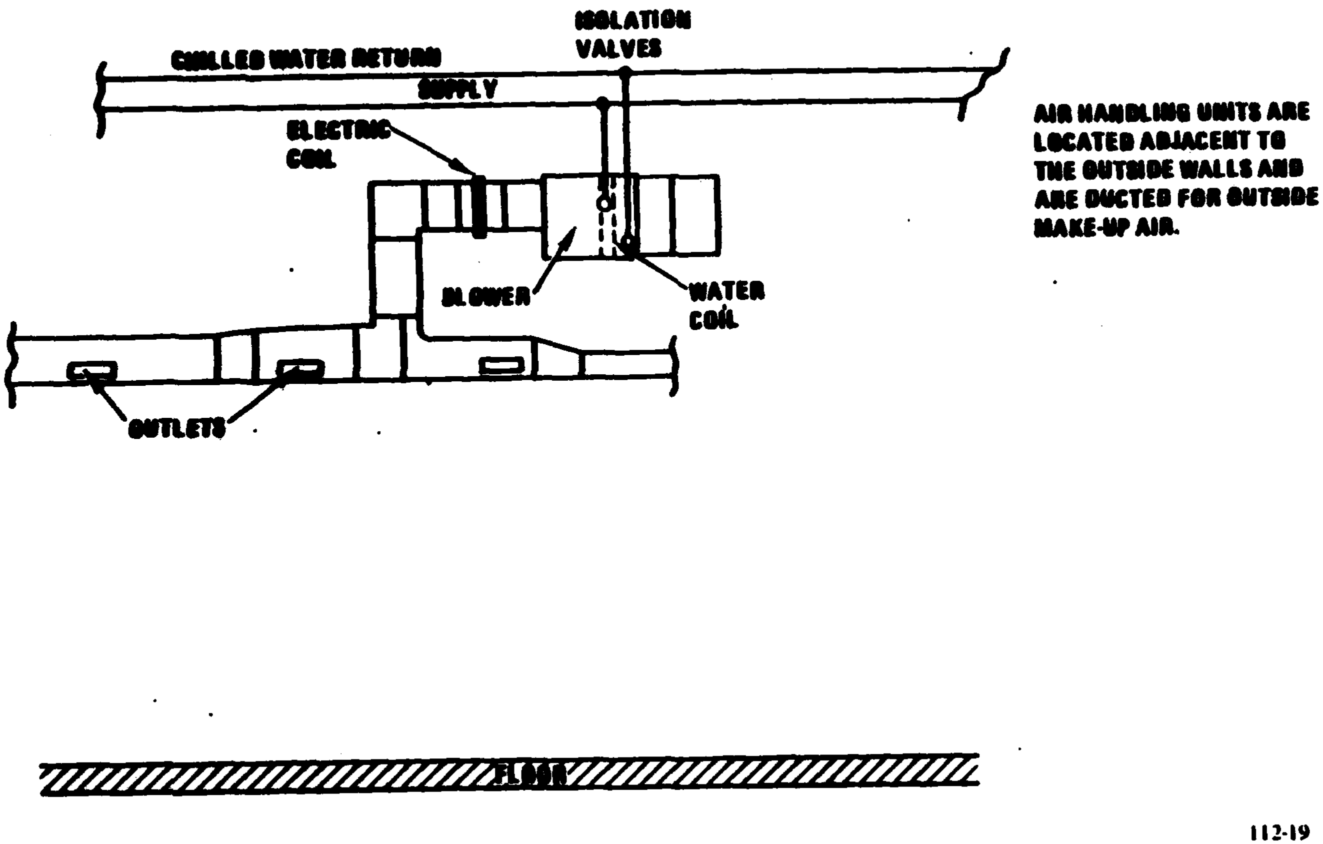

Figure 6-5. Existing Environment Conditioning System - Air Force Musuem (Bldg. No. 489), Wright-Patterson AFB

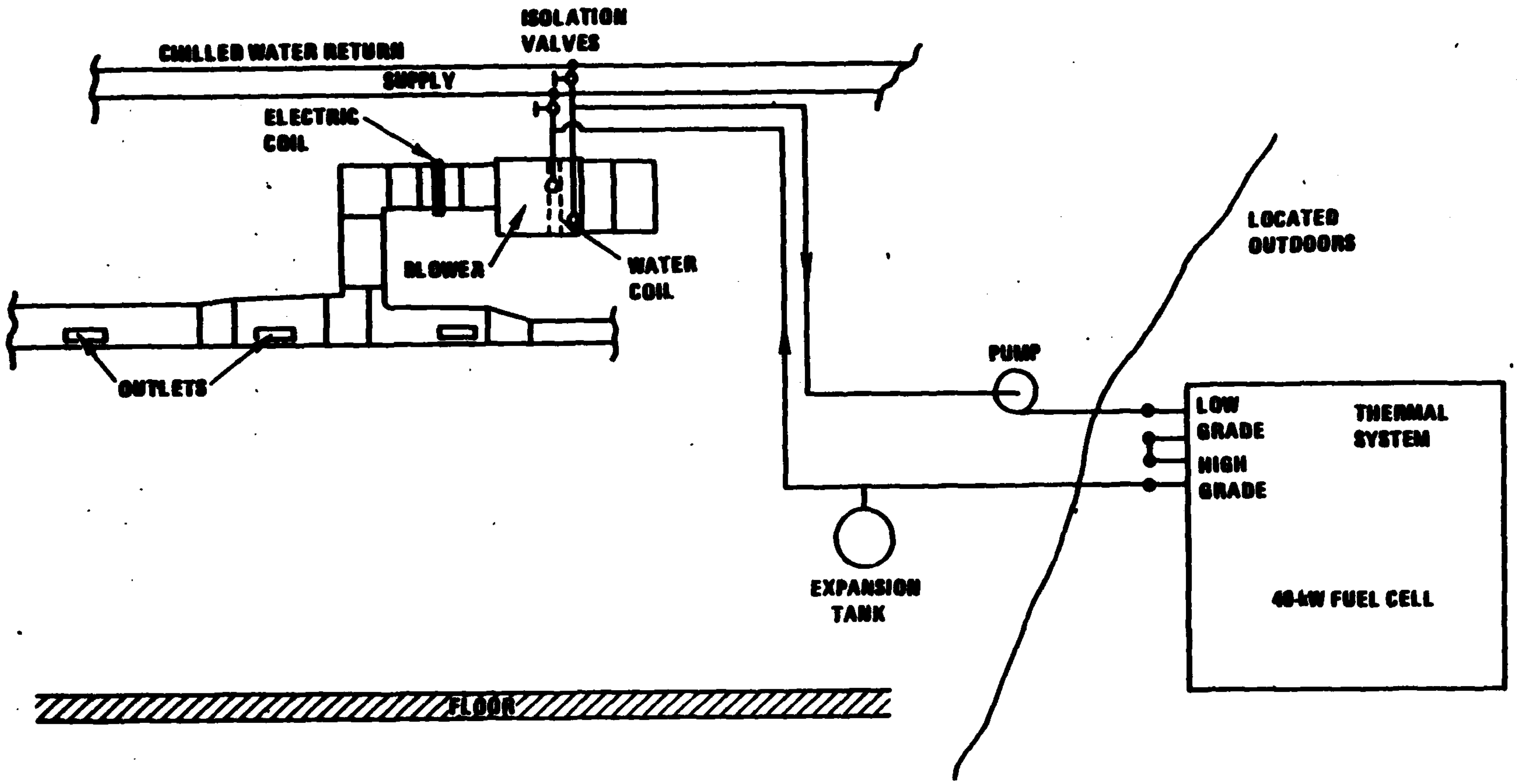

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Figure 6-6. Conceptual Integration Design - Air Force Museum (Bldg. No. 489), Wright-Patterson AFB

heaters in those air handling units which are near where the fuel cell is to be located should be monitored continuously during the heating season. Indoor and outdoor temperatures should also be monitored.

ELECTRICAL SYSTEM - ALL SITES

Since the fuel cell will be integrated with the electric utility grid the electrical interface will be common to all sites. A one-line electrical diagram of this system is shown in Figure 6-7. The fuel cell is designed for 208/120V, 3 phase output. An optional transformer can be installed to match the existing building service. During conditions when normal electric utility service to the building is interrupted, the fuel cell can provide up to 40-kW to a suitably sized isolated load within the building. Under these conditions switch SW1 (Figure 6-7) will be open and SW2 will automatically connect the isolated load to the fuel cell. The fuel cell must be manually reset to reconnect to operation with the utility grid.

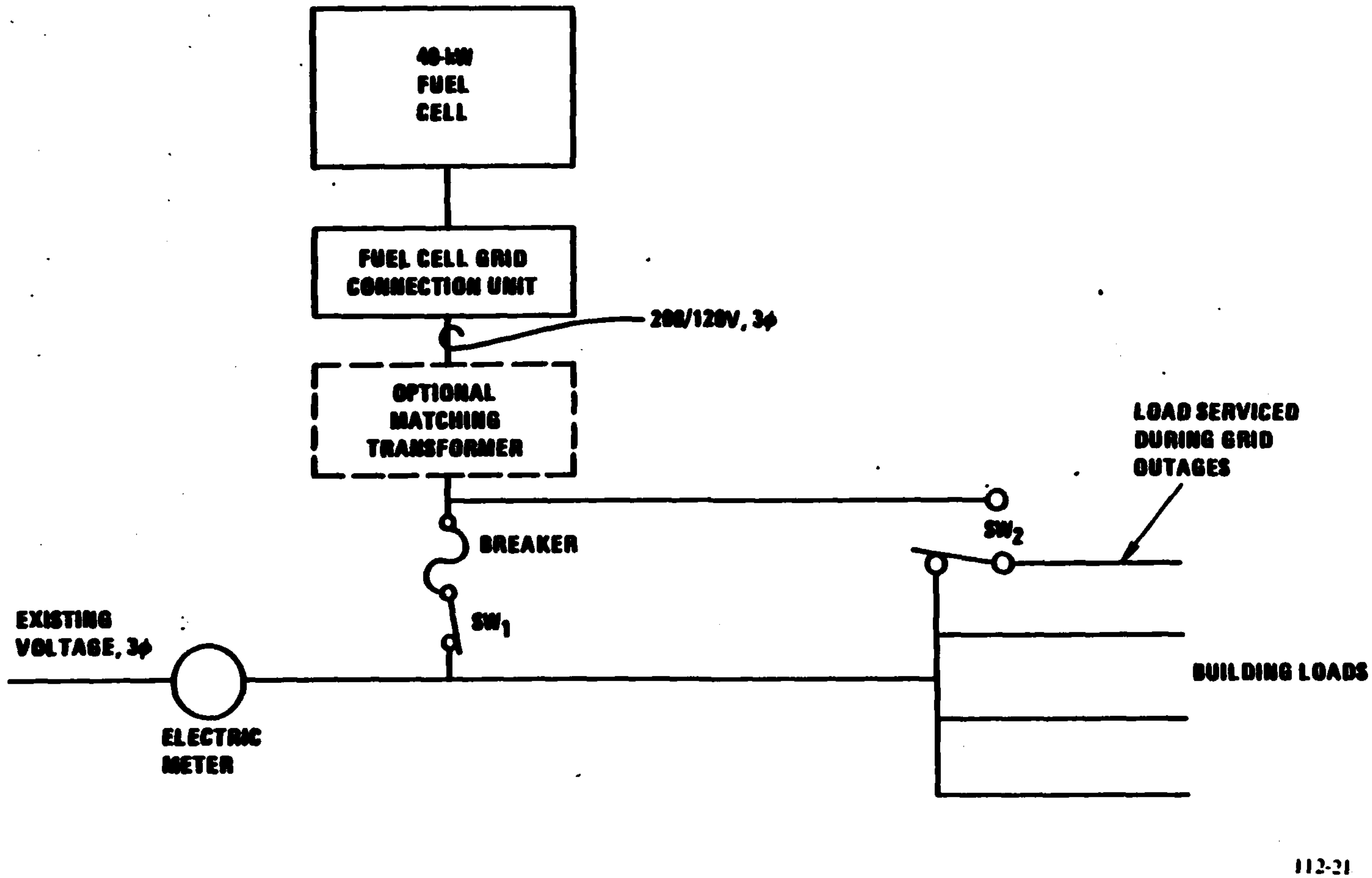


Figure 6-7. Electrical Design System - All Sites

Section 7
REFERENCES

1. "On-Site 40 Kilowatt Fuel Cell Power Plant Model Specification," FCS-1460, prepared by United Technologies Corporation for Department of Energy and Gas Research Institute, September 4, 1979.

APPENDIX A

ON-SITE 40-KW FUEL CELL PROGRAM

SURVEY BUILDING ANALYSIS
GRID-CONNECTED OPERATION
CONTINUOUS FULL POWER

OUTPUT FORMAT

SITE BUILDING DATA

. DEFINITIONS	- TABLE 1*
. SITE BUILDING DATA LISTING	- TABLE 2*
. STATISTICAL ANALYSIS BY BUILDING TYPE	- TABLE 3

ENERGY AND ECONOMIC ANALYSIS - FUEL CELL HEAT RECOVERY SYSTEM, GRID-CONNECTED OPERATION

INFINITE FUEL CELL CATALOG

. SITE LISTING	- TABLE 4
. ALLOWABLE COST RANKING, GRID & ISOLATED OPERATION	- TABLES 5 & 6
. PERCENT CUSTOMER SAVINGS RANKING, GRID & ISOLATED OPERATION	- TABLES 7 & 8
. PERCENT RESOURCES CONSERVED RANKING, GRID & ISOLATED OPERATION	- TABLES 9 & 10

40KW CATALOG ONLY (UP TO 2 FUEL CELL POWERPLANTS)

. SITE LISTING	- TABLE 11*
. ALLOWABLE COST RANKING, GRID & ISOLATED OPERATION	- TABLES 12 & 13
. PERCENT CUSTOMER SAVINGS RANKING, GRID & ISOLATED OPERATION	- TABLES 14 & 15
. PERCENT RESOURCES CONSERVED RANKING, GRID & ISOLATED OPERATION	- TABLES 16 & 17

*INCLUDED WITH AIR FORCE STUDY

DEFINITIONS - TABLE I

UTILITY	BUILDING TYPE	AVAILABLE OUTPUT PARAMETERS	
1 AMERICAN NATURAL	A APARTMENT	1 HDAY	HEATING DEGREE DAYS-65 BASE
2 ATLANTA GAS LIGHT	B BANK	2 CDAY	COOLING DEGREE DAYS-75 BASE
3 BROOKLYN UNION	C SHOPPING CEN	3 FT2	FLOOR AREA
4 CANADIAN WESTERN	D STORE	4 UNIT	REST.- SEATS,APTS.- UNITS,NURS.HOMES- BEDS,HOSP.- BEDS
5 COLUMBIA GAS	E CHURCH	5 KW	PEAK 30 MIN. DEMAND
6 CONN. NATURAL	F FAST FOODS	6 TON	AIR CONDITIONING CAPACITY
7 CONSOLIDATED NAT	G GROCERY	7 ANNUAL T	ANNUAL GAS USE- MCF
8 CONSUMERS POWER	H HOSPITAL	8 T MBTU/F	ANNUAL GAS USE PER FLOOR AREA
9 EL PASO NATURAL	I INDUSTRIAL	9 MCF/U	ANNUAL GAS USAGE PER UNIT
10 INTERMOUNTAIN	J DORMITORY	10 ANNUAL E	ANNUAL ELECTRIC USE- KWH
11 KANSAS-NEBRASKA	K	11 E MBTU/F	ANNUAL ELECTRIC USE PER FLOOR AREA-MBTU/FT2
12 MINNEAPOLIS	L LAUNDRY	12 KWH/U	ANNUAL ELECTRIC USE PER UNIT
13 NATIONAL FUEL GAS	M MOTEL/HOTEL	13 T/E	RATIO:GAS USE/ELECTRIC USE (DIMENSIONLESS)
14 NORTHERN ILLINOIS	N NURSING HOME	14 LF	ANNUAL AVERAGE BUILDING ELECTRIC LOAD FACTOR
15 OKLAHOMA NATURAL	O OFFICE	15 KW/U	PEAK 30 MIN. DEMAND (KW) PER UNIT
16 PEOPLES GAS LIGHT	P HOME	16 TON/U	AIR CONDITIONING CAPACITY PER UNIT
17 SOUTHERN CALIF.	Q	17 FT2/U	FLOOR AREA PER UNIT
18 SOUTHERN UNION	R RESTAURANT	18 KW/FT2	PEAK 30 MIN. DEMAND (KW) PER FLOOR AREA
19 WASHINGTON GAS	S	19 TONS/FT2	AIR CONDITIONING CAPACITY PER FLOOR AREA
20 OSAKA GAS	T	20 RES/FT2	RESOURCES(MBTU) /FLOOR AREA (32% POWER GEN EFF)
21 TOKYO GAS	U UNIVERSITY	21 RES/U	RESOURCES(MBTU) PER UNIT (32% POWER GEN EFF)
22 MOUNTAIN FUEL	V SCHOOL	22 T+E	TOTAL ENERGY USAGE PER FLOOR AREA- MBTU/FT2
23 SAN DIEGO G & E	W WAREHOUSE	23 YR	CALENDAR YEAR
24 PACIFIC G & E	X HEALTH CLUB	24 LG MOTOR	LARGEST MOTOR RATING-KW
25 RICHMOND GAS	Y	25 ELEC CF	FUEL CELL ELECTRIC CAPACITY FACTOR
26 PUBLIC SERVICE	Z MISC.	26 THRM CF	FC THERMAL CAPACITY FACTOR = (Q USED)/(FCPK)(8760)
27 NORTHERN NATURAL		27 FUELUTIL	OVERALL FUEL CELL FUEL UTILIZATION
28 BOSTON GAS		28 HEATSUPP	FRACTION OF BUILDING HEAT SUPPLIED BY FUEL CELL
29 MEMPHIS LT GS WTR			
30 FLORIDA POWER			
31 NORTHWEST NAT			
32 PACIFIC RESOURCE			
33 GEORGIA POWER			
34 BALTIMORE G & E			
35 CENTRAL HUDSON			
36 DAYTON POWER			
37 NORTHEAST UTIL			
38 GASCO (HAWAII)			
0 AIR FORCE BASES			

DEFINITIONS - TABLE 1 (CONT'D)

DEFINITION OF CODES

B - BUILDING TYPE
HC- HEAT AND COOLING SYSTEMS
SI- SYSTEM INTERFACE
SR- SPECIAL REQUIREMENTS

HEAT/COOL SYSTEM FUEL (HC)

HEAT (H)

C COAL
E ELECTRIC
G GAS
M MIXED
S STEAM
O OIL
U UNKNOWN

COOL (C)

A ABSORPTION
E ELECTRIC
M MIXED
U UNKNOWN
V EVAPORATIVE
N NONE

SPACE HEATING SYSTEM INTERFACE (SI)

1 2 PIPE FAN- COIL H/C*
2 GAS/ELECTRIC FURNACE*
3 ELECTRIC BASEBOARD
4 HOT WATER BASEBOARD
5 UNIT HEATERS- GAS/ELECTRIC
6 UNIT HEATER- STEAM
7 UNIT HEATER- HOT WATER
8 INCREMENTAL ELECTRIC- AIR
9 INCREMENTAL ELECTRIC- WATER*
10 PACKAGED AIR COND., HEAT*
11 RADIANT PANEL HEAT- ELECTRIC
12 RADIANT PANEL HEAT- HOT WATER*
13 HEAT PUMP

SPECIAL REQUIREMENTS (SR)

1 COMPUTER
2 LARGE MOTOR
3 X-RAY
4 ELEVATORS
5 LARGE INCOMPATIBLE GAS USE
6 INSTITUTIONAL QUESTION
7 FACILITIES LIMITATION
8 ESTIMATED ENERGY USE
9 OWNER LIMITATIONS
10 DC POWER REQUIREMENT
11 PROCESS HOT WATER LOAD
12 LOAD MANAGED TO 80 KW

RANKING PARAMETERS

ALLOW COST - ALLOWABLE FUEL CELL COST BASED ON EQUIVALENT COST OF CUSTOMER SERVICE
% RES CONS- % RESOURCES CONSERVED BASED ON CONVENTIONAL GENERATING EFFICIENCY OF 32%
% COST SAVINGS- % CUSTOMER SAVINGS BASED ON A FUEL CELL INSTALLED COST OF 500 $/KW

ECONOMIC ANALYSIS ASSUMPTIONS

. GRID CONNECTED OPERATION
. UTILITY OWNERSHIP OF FUEL CELL ENERGY SYSTEM
. FUEL CELL COST INCLUDES HEAT EXCHANGER COST AND/OR HEAT PUMP COST

BUILDING DATA SUMMARY - TABLE 2 (SEE TABLE 1 FOR DEFINITIONS)

BUILDING TYPE(S): ALL UTILITY : ALL
HEAT CODE(S) : ALL HDDAYS : ALL
COOL CODE(S) : ALL YEARS : ALL

-SITE NO- UTIL CODE	UTC CODE	SIC CODE	STATE	GAS CO.	HC	HDAY	CDAY	SI CODE	SR CODE	FLOOR AREA FT2	UNITS	PEAK DEMAND-KW YEAR	PEAK DEMAND-KW WINTER	LARGEST MOTOR (KW)	A/C TONS	ANNUAL GAS USE	ANNUAL ELECT USE	T/E	ELECTRIC LOAD FACTOR	YR	TYPE
262	1	0	OH	0	SE	5455	686	6	841	544402	0	4500	3000	0	2044	1700	16000000	0.0	0.41	82	AFLC HQTR
825	2	0	OH	0	SE	5455	686	1	84	99611	210	300	150	0	150	3425	740000	1.4	0.28	82	VSTOFFQTR
826	3	0	OH	0		5455	686		8	77823	180	275	140	0	0	3090	700000	1.3	0.29	82	VSTOFFQTR
849	4	0	OH	0	SE	5455	686	6	811	45806	0	60	60	0	30	2350	350400	2.0	0.67	82	OFFCR GYM
489	5	0	OH	0	EE	5455	686	5	8	228440	0	900	375	0	746	16645	2826000	1.7	0.36	82	AF MUSEUM *
1240	6	0	OH	0		5455	686		811	34434	0	1600	1600	0	0	2650	12000000	0.1	0.86	82	HEATPLANT
127	7	0	OH	0		5455	686		8	23571	800	100	60	0	0	980	224000	1.3	0.26	82	CAFETERIA
1214	8	0	OH	0		5455	686		8	14270	999	100	60	0	0	2290	280000	2.4	0.32	82	AR DINING
830	9	0	OH	0		5455	686		38	0	400	1800	1200	0	0	15500	6450000	0.7	0.41	82	HOSPITAL
521	11	0	UT	0	S	6255	397	1	8	18000	120	97	0	6	52	1565	237000	1.9	0.28	82	AIRM DORM
570	12	0	UT	0	S	6255	397		348	81000	0	188	0	19	0	4700	675000	2.0	0.41	82	HOSPITAL
505	13	0	UT	0	S	6255	397		108	57600	30	1080	0	0	0	204000	7638000	7.8	0.81	82	ELECPLATE
644	21	0	GEO	0	G	2253	727		8	5693	0	293	293	150	0	241816	694920	102.0	0.27	82	HEATPLANT

NUMBER OF SITES = 13

UTC BUILDING IDENTIFIER

WRIGHT-PATTERSON AFG (1-9)
HILL AFB (11-13)
ROBINS AFB (21)

AIR FORCE BUILDING IDENTIFICATION NO.

EQUIVALENT ANNUAL
FUEL CONSUMPTION
(10^6 Btu/YEAR)

ANNUAL
ELECTRIC
(kWh/YEAR)

*AIR FORCE MUSEUM MODELED AS EQUIVALENT GAS HEATED BUILDING. ACTUAL DATA WERE:

ELECTRIC DEMAND	YEARLY	1855 kW
	WINTER	1855 kW
ANNUAL GAS USE		0
ANNUAL ELECTRIC USE		5,995,094 kWh/YEAR
T/E RATIO		0
ELECTRIC LOAD FACTOR		0.37

CANDIDATE SITES

TABLE 11

FUEL CELL HEAT RECOVERY SYSTEM - GRID-CONNECTED OPERATION, OPTION 2

SITE NUMBER LISTING

40KW CATALOG ONLY (UP TO 2 FUEL CELL POWER PLANTS) WITH SURVEY UTILITY RATES

RANK NO.	SITE NO.	GAS CO.	CODES B	CODES HC	CODES SI	CODES SR	YR DEM KW	FC SIZE KW	FC ELEC CF	FC THERM CF	FC FUEL UTIL	FC HEAT SUPP	T/E	ELEC RATE CONV (¢/KWH)	ELEC RATE BUY (¢/KWH)	ELEC RATE SELL (¢/KWH)	GAS RATE CONV ($/MCF)	GAS RATE FC ($/MCF)	ANNUAL ELECT USE (KWH)	NET ELECT BUY (KWH)	ALLOW COST $/KW	%RES CONS BTU
1	1	0	O	SE	6	041	4500	40	1.00	0.57	0.56	0.65	0.0	4.43	4.43	4.43	3.65	3.65	16000000	15649600	1908	0.0
2	2	0	J	SE	1	04	300	40	1.00	0.55	0.55	0.31	1.4	4.43	4.43	4.43	3.65	3.65	740000	389600	1864	12.1
3	3	0	J			0	275	40	1.00	0.54	0.55	0.34	1.3	4.43	4.43	4.43	3.65	3.65	700000	349600	1853	12.0
4	4	0	X	SE	6	011	60	40	1.00	0.79	0.64	0.65	2.0	4.43	4.43	4.43	3.65	3.65	350400	0	2418	30.0
5	5	0	Z	EE	5	0	900	40	1.00	0.70	0.61	0.08	1.7	4.43	4.43	4.43	3.65	3.65	2826000	2475600	2220	3.6
6	6	0	I			011	1600	40	1.00	0.49	0.53	0.36	0.1	4.43	4.43	4.43	3.65	3.65	12000000	11647600	1720	1.0
7	7	0	R			0	100	40	1.00	0.30	0.49	0.75	1.3	4.43	4.43	4.43	3.65	3.65	224000	-126400	1465	21.0
8	8	0	R			0	100	40	1.00	0.61	0.57	0.52	2.4	4.43	4.43	4.43	3.65	3.65	280000	-70400	2015	24.7
9	9	0	M			30	1000	40	1.00	0.61	0.57	0.08	0.7	4.43	4.43	4.43	3.65	3.65	6450000	6099630	2014	1.0
10	11	0	J	S	1	0	97	40	1.00	0.50	0.53	0.63	1.9	5.50	5.50	5.50	2.27	2.27	237000	-113400	4077	24.0
11	12	0	M	S		340	100	40	1.00	0.75	0.62	0.31	2.0	5.50	5.50	5.59	2.27	2.27	675000	324600	4438	14.0
12	13	0	I	S		100	1000	40	1.00	0.89	0.67	0.01	7.8	5.50	5.50	5.50	2.27	2.27	7638000	7287600	4629	0.7
13	21	0	I	6		0	293	40	1.00	0.89	0.67	0.01	102.0	5.40	5.40	5.40	3.60	3.60	694920	344520	3774	0.0

FUEL CELL ELECTRIC CAPACITY FACTOR CONTINUOUS FULL POWER (1.0.)

ESTIMATE OF FRACTION OF FUEL CELL HEAT UTILIZED IN BUILDING

FUEL CELL FUEL UTILIZATION, FRACTION OF FUEL INPUT UTILIZED AS ELECTRICITY OR HEAT IN BUILDING

FRACTION OF BUILDING THERMAL REQUIREMENT SATISFIED BY ONE 40 kW FUEL CELL

BREAKEVEN INSTALLED FUEL CELL PRICE FOR EQUAL COST OF SERVICE (OWNING CHARGE 7.7%/YR)

RESOURCE CONSERVATION SAVINGS FOR ENTIRE BUILDING (LOW VALUES INDICATE F/C OUTPUT SMALL COMPARED WITH TOTAL BUILDING USE)

APPENDIX B

SITE SELECTION CRITERIA AND ENERGY REQUIREMENTS SURVEY FORMAT

Fuel Cell Site Selection for Air Force Base Application

I. Background

Recent Presidential and Congressional directives require the Department of Defense to implement programs which will limit petroleum consumption through increased conservation and the use of alternative fuel sources. Energy self sufficiency goals have also been issued by the Air Force Logistics Command (AFLC) for its Air Logistics Centers. Through analysis and development programs, the Air Force Systems Command has identified fuel cell on-site energy conversion systems as a potential superior method to satisfy these requirements.

The most effective and economical use of natural resources can be accomplished by locating an efficient electrical generation system adjacent to the energy load and fully utilizing the "waste" heat which is a by product of any energy conversion process. The potential of on-site energy systems has not yet been realized because available power plants are not economical at power plant ratings which match typical site requirements. The operating performance of conventional equipment is further reduced at low part-load settings. Noise and pollution from conventional equipment limits the number of sites at which the equipment can be located or leads to increased installation expense. The fuel cell is a primary candidate for solving these problems. The fuel-to-electrical conversion process is electrochemical and involves no moving parts or high temperatures. The fuel cell's efficiency is the highest of any available on-site system at full or part load. Exhaust emissions are orders of magnitude lower than present Environmental Protection Agency standards. The power plant is very quiet, producing noise levels equivalent to residential background levels.

Currently the Department of Energy (DOE), the Gas Research Institute and member gas utilities, are funding a major operational fuel cell field test program through the United Technologies Corporation (UTC). The 40kW On-Site Fuel Cell Operational Feasibility Program will result in the evaluation of up to 45 UTC fuel cell power plants through the United States (Figure 1) and Japan.

The Department of Defense, in cooperation with DOE, is funding the field testing of four additional power plants. One of these power plants is to be tested at Sheppard AFB, Texas. Operation of this unit will provide a basis for evaluating the potential of this new energy technology at other Air Force installations. It is believed that some utilities participating in this program are also interested in testing fuel cells on Air Force installations which they service. Your base is being examined as a potential site for installation of one of these 40kW fuel cells.

II. Application Data Request

The purpose of this communication is to obtain information and data defining specific candidates applications at your base. This data will be evaluated by United Technologies Corporation and will provide the necessary information to allow HQ AFLC/DE to identify facilities for potential operational testing and provide assessment of the future economic and

operational benefits of commercial fuel cell power plants..

In order to make best possible use of analysis techniques previously developed to assess fuel cell electric and thermal compatibility within specific applications you are requested to utilize the standard survey data questionaire forms provided. The following sections of this document will review the on-site fuel cell power plant characteristics, a recommended fuel cell system configuration and suggested site selection criteria. Based upon these inputs please define a minimum of 5 Air Force applications which you feel would be suitable fuel cell demonstration sites. Please fill out one of the attached questionaires for each site. Along with the completed questionaire include a one-line diagram or sketch of the present thermal system with your view as to how the fuel cell might be integrated. Mail this material to the address noted on the survey form.

III. Fuel Cell Power Plant Characteristics

Fuel cell power plants offer very positive characteristics, such as negligible air pollution, quiet, vibration free operation, which should increase available siting opportunities. In addition, the power plant is designed for all weather and unattended operation. These features should permit roof top or ground level, indoor or outdoor installation in many locations. Because of these "good neighbor" features the primary emphasis on site selection will generally concentrate on locating applications which can fully utilize the energy conversion capabilities of the fuel cell.

As indicated in attached reference, "On-Site 40 Kilowatt Fuel Cell Power Plant Model Specification", the fuel cell will simultaneously generate up to 40kW, 60Hz electric power and recoverable thermal energy. The fuel source is pipeline natural gas or peak shaved gas. The power plant may be connected in parallel with the electric utility grid or it may be operated isolated from the grid. When in grid connected operation the power plant may be automatically switched to handle an isolated critical load should there be an interruption in normal utility service.

Two sources of recoverable heat in the form of hot water are available from the power plant. A high grade supply is available at temperatures up to 275^{o}F and represents roughly one-third (50,000 Btu/Hr.) of the total recoverable heat at full power output. Delivery of high grade heat to the thermal load is controlled by the power plant and is only delivered as it becomes available from an internal cooling system. A 3-way valve in the power plant will bypass the high grade heat exchanger when high grade heat is not available. During bypass the exist temperature will roughly equal the inlet temperature.

Low grade heat is also available from the power plant. Assuming a return to the power plant of 80^{o}F, design conditions 100,000 Btu/Hr of low grade heat is available at a supply temperature of 160^{o}F. The fraction of this heat that can be recovered and the supply temperature is controlled by the customer supplied return temperature and flow rate to the power plant.

IV. Fuel Cell System Configuration

The most favorable Air Force applications will be those in which maximum advantage is taken in the utilization of the fuel cell's electrical and thermal energy.

Since the installed power plant capacity would generally be small relative to the base electric requirement, the power plant would be operated at full power in a grid connected configuration. Sizing for a nearly continuous thermal load would insure full use of the recoverable heat operating at full power. Electricity generated in excess of the site requirements would be used within the base and would contribute to a reduction in purchased electricity. Conventional utility service would satisfy site electrical needs during power plant maintenance.

Because the fuel cell automatically switches to isolated operation in the event of a conventional utility power outage additional benefits could be derived by having the fuel cell service critical electric loads. The high and low grade heat sources are independent systems and can be installed to handle independent loads. In applications where large hot water or process loads exist both heat sources would be linked in series to simplify the installation and still make full use of fuel cell heat. Makeup water would be first passed through the low grade heat exchanger. Heat delivered in this heat exchanger is a strong function of supply temperature. Makeup water supplied at cool ground temperature levels will maximize the heat delivered. Flow from the low grade source would then be directly fed to the high grade heat exchanger. High grade heat delivery is not a strong function of supply temperature and thus will deliver all of the heat available at the operating power levels. An example of this system is shown in Figure 2.

In the event that the application thermal requirement is discontinuous a thermal storage device may be employed. This system is shown in Figure 3. Note that makeup water is plumbed such that it will first pass through the low grade heat exchanger. This configuration insures maximum heat delivery by keeping the heat recovery system supply temperature to the fuel cell as low as possible.

Depending upon the application requirements a number of other system configurations are possible. Figure 4 illustrates an application with both a domestic hot water and a process heat requirement. The thermal requirements are supplied independently by the fuel cell. The constant temperature bath is a good application of the high grade supply.

V. Site Selection Criteria

To insure that the applications to be evaluated will best meet the needs of the Air Force the following criteria should be used in their selection:

a. Site should be suitable for display and demonstration to selected Air Force personnel and the public. Consideration should be given to aesthetics, safety and visitor facilities.

b. Representative of a class or type of application common to the Air Force and commercial applications. This will help foster local utility interest in a demonstration.

c. Suitable location for the fuel cell in a reasonable proximity to the site thermal load. Thermal load should be temperature compatible and as nearly continuous as possible requiring 150,000 BTU per hour or nearly 110 million BTU per month. Thermal storage may be utilized to improve coincidence.

d. Voltage and other electrical interface conditions should be compatible with power plant specification.

e. Natural gas supply should be near the site.

f. It would be desirable if the application has a requirement for backup emergency power of less than 40 kilowatts.

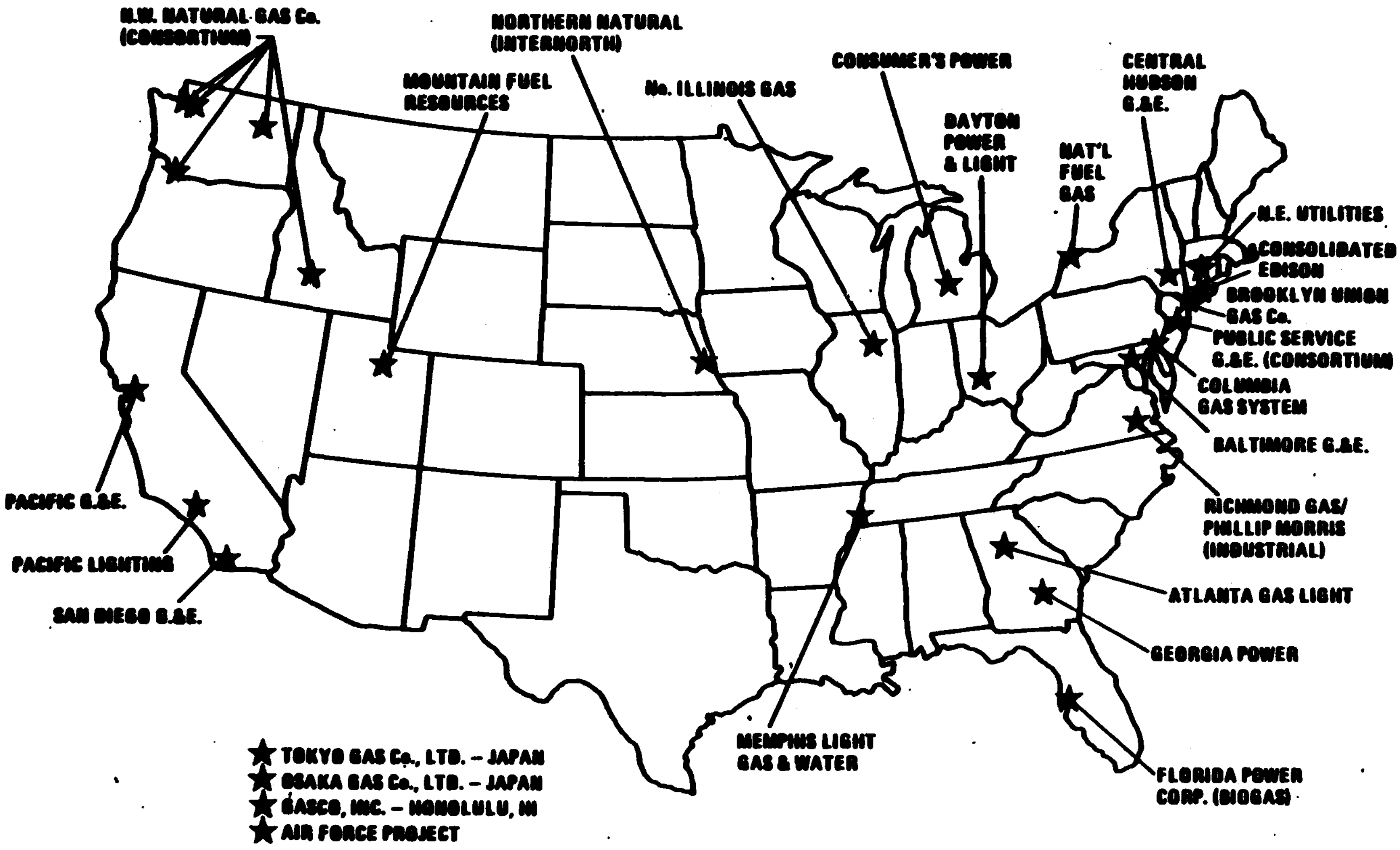


Figure 1. Participating Utilities

UNITED TECHNOLOGIES POWER SYSTEMS

FC16566
R812509

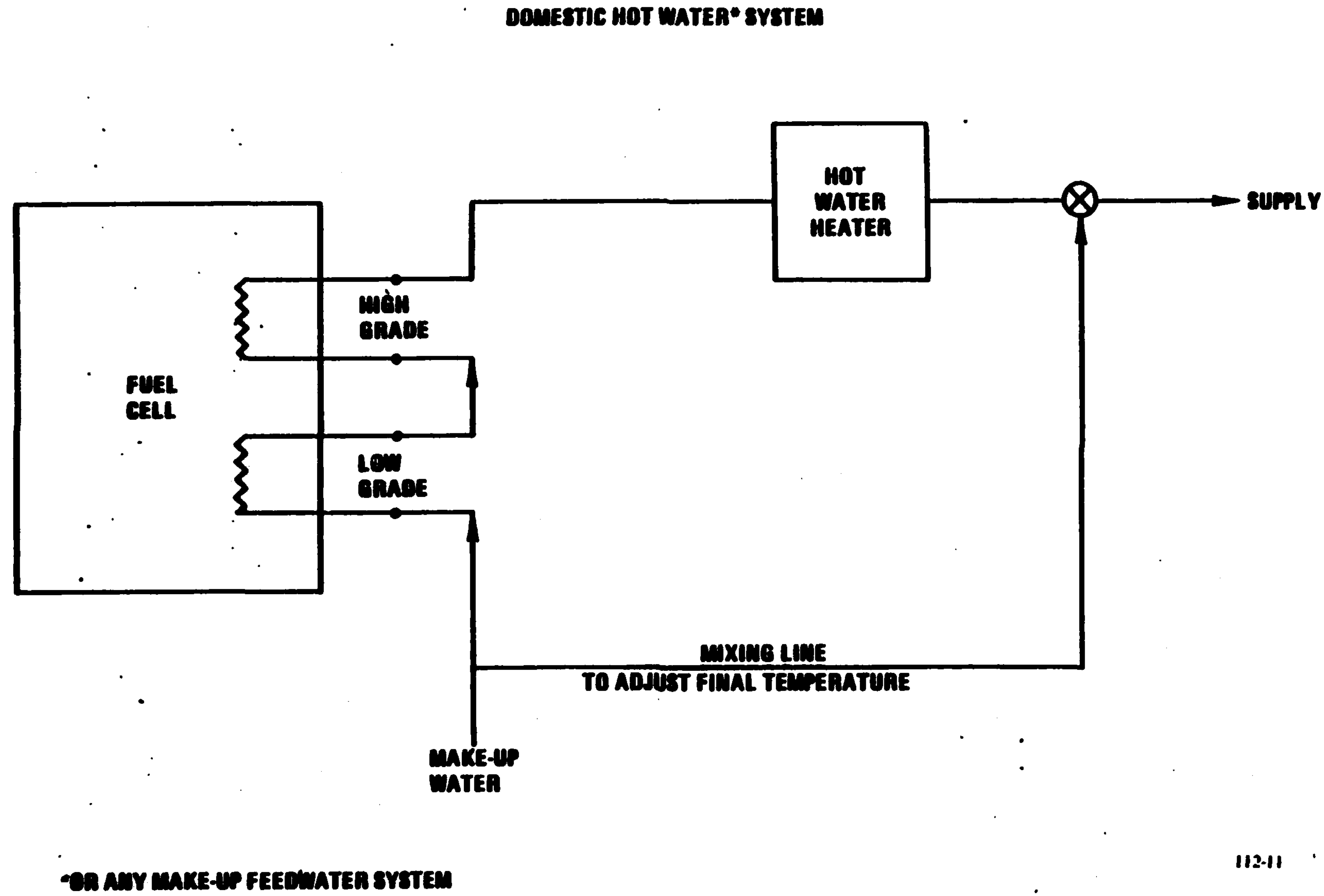
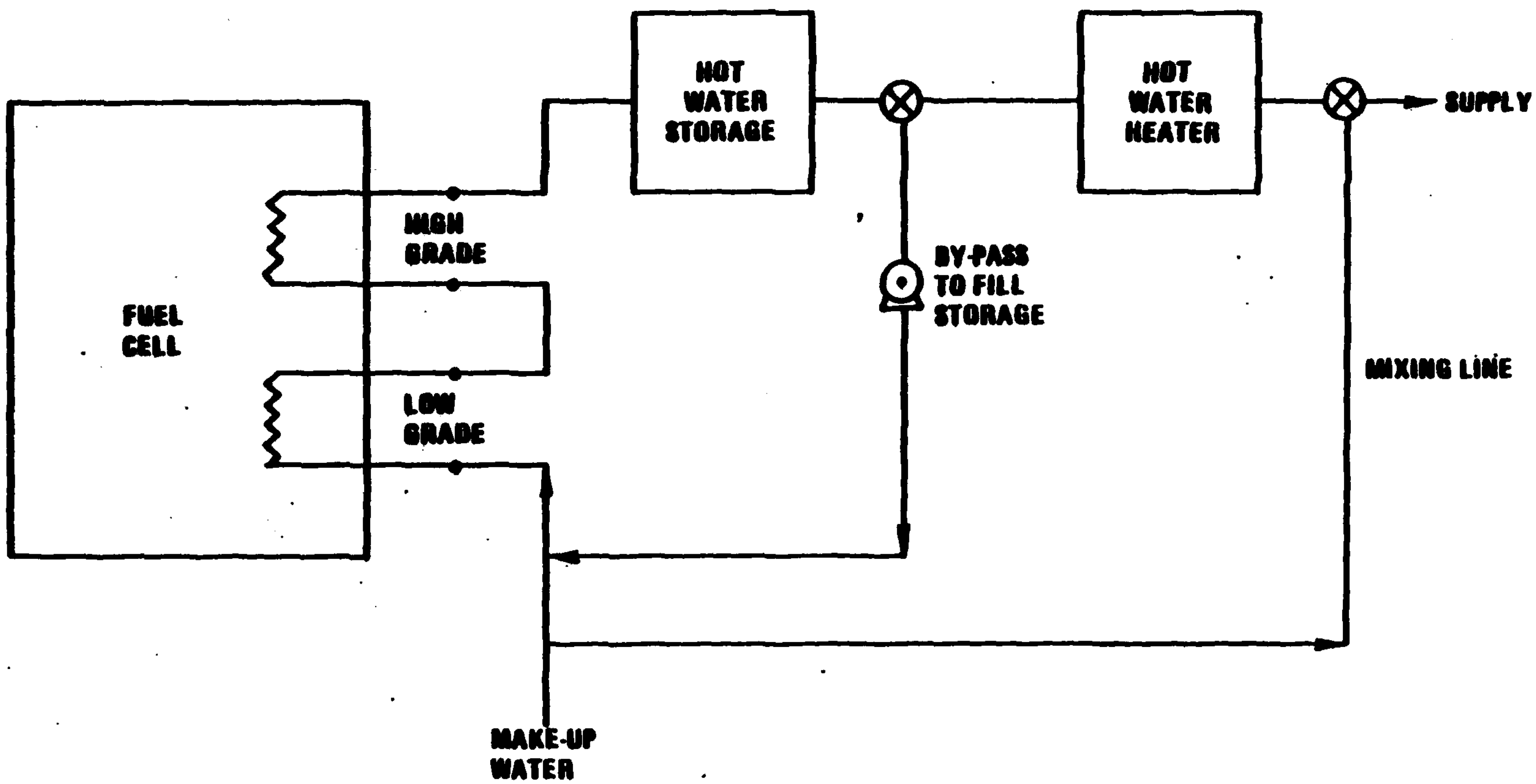


Figure 2. Typical Fuel Cell Thermal Interface with a Domestic Hot Water System

DOMESTIC HOT WATER* SYSTEM WITH THERMAL STORAGE



*OR ANY MAKE-UP FEEDWATER SYSTEM

Figure 3. Typical Fuel Cell Thermal Interface with Storage Interfaced with a Domestic Hot Water System

PARALLEL THERMAL SYSTEM

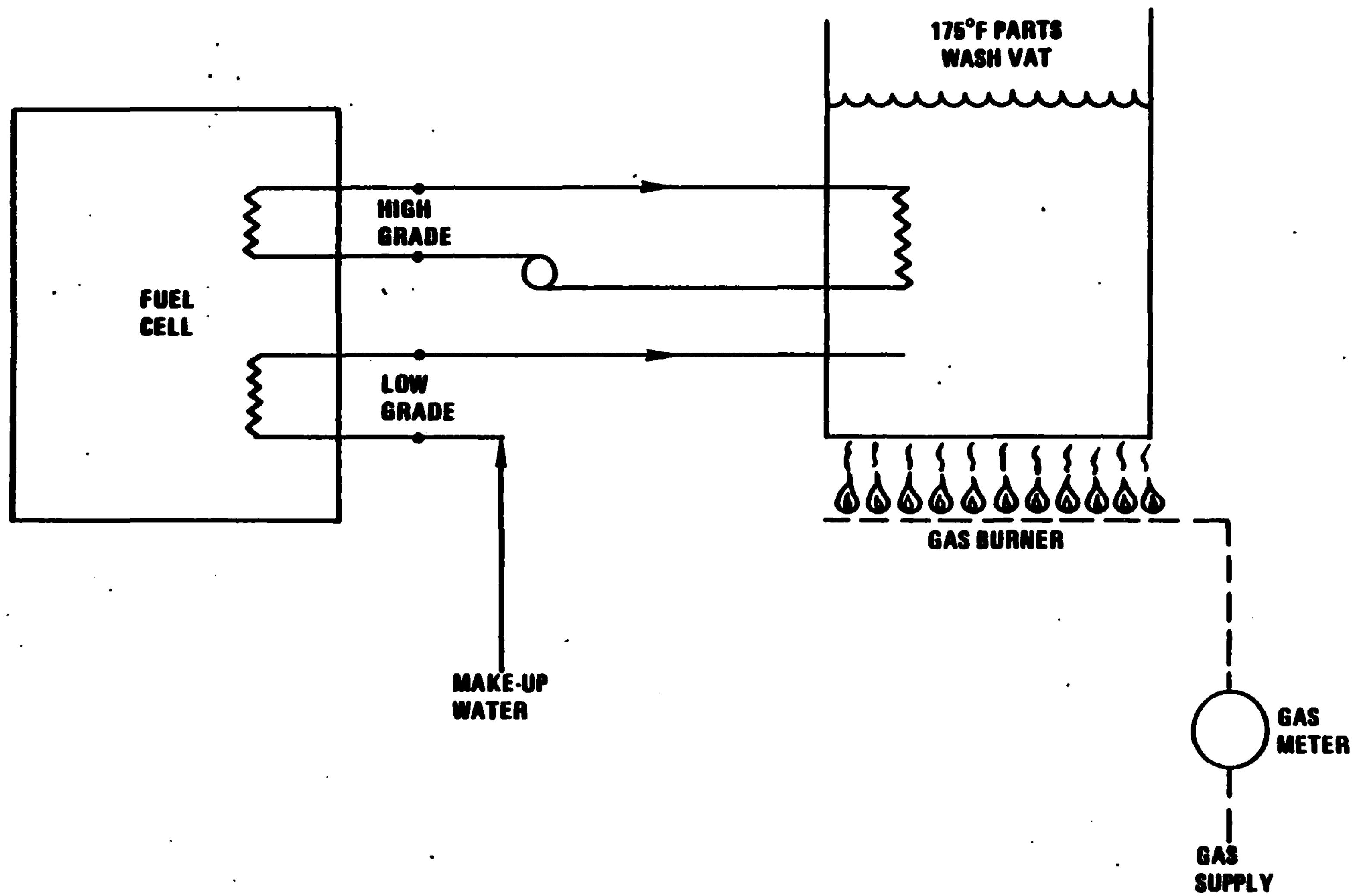


Figure 4. Example Fuel Cell Thermal Interface with Independent Loads

DATA SURVEY FORM
FOR AIR FORCE APPLICATIONS
COMPATIBILITY WITH FUEL CELL ENERGY SERVICE

Please complete this form for each application and send to:

Mr. J. W. Staniunas
United Technologies Corp.
P.O. Box 109
South Windsor, Conn. 06074

(203) 727-2307

Air Force Base ______________________________

Site Number ______________________________

Address ______________________________

Name of person
completing form ______________________________

Telephone No. ______________________________

1. Building use for ______________________________

____

____

2. <u>Description of building</u>:

a. Floor area ______________ ft^2

b. Other size descriptor (i.e., # of dwelling units) __________

c. Hours of use and % occupied: Weekdays ______________

Saturday ______________

Sunday ______________

d. General Building construction (# of floors, shape, age, materials)

____

____

e. Is there space for a structure approximately 12' x 15' on the site? Where?

____

____

3. <u>Electric Service</u>

Service 1) Rating: _____ Amps, _____ Volts _____ Phase, _____ Wires

Service 2) _____ _____ _____ _____

4. <u>Electrically Sensitive Equipment in Building</u>

Computer ☐	Manufacturer	________	Model# ______
Word Processor ☐		________	______
X-Ray Machine ☐		________	______
Other ☐	________ (Specify)	________	______

5. Other Major Equipment

a. Elevator Manufacturer____________________

Number__________; Speed______________; Capacity____________

Drive Type: Hydraulic ☐ , Direct AC Motor ☐ ,

AC Motor/DC Generator/DC Motor ☐

b. D.C. Equipment ☐ Type:____________________

Capacity:____________________

c. Electric Motors (Complete for all motors 3 H.P. and over)

	OBTAIN FROM MOTOR NAMEPLATE						
Function	1 or 3Ø	Voltage	H.P.	NEMA Letters Design	NEMA Letters Code	FLA	LRA
1.							
2.							
3.							
4.							

6. Air Conditioning System

a. System Type: Electric Vapor Compression ☐

Gas Absorption ☐

Evaporative Cooling ☐

b. System Configuration

Unitary ☐ Remote Chiller/Air Handler ☐

Split ☐ Window ☐

Other ☐ Describe:____________________

c. Manufacturer____________________ Model#____________________

No. of Identical Units____________

Rating (tons, Btu/hr) ____________ or (CFM) ____________

7. Space Heating System

a. System Fuel (i.e. Gas, Oil, Coal, Electric) ____________________

b. System Type

Forced Air ☐

Steam ☐ a. Radiators ☐ b. Central Air Handlers

☐ c. To Hydronic

Hydronic ☐ a. Baseboard ☐ b. Fan-Coil

☐ c. Convectors

Radiant ☐ a. Walls ☐ b. Floor ☐ c. Ceiling

Heat Pump ☐ a. Air Source ☐ b. Water Source

Unit Heaters ☐

Other ☐ Describe: ____________________

c. Capacity (Btu/hr. Kwe) ____________________

d. Water Supply and Return Temperatures (if applicable) ___°F, ___°F

e. Steam supply pressure __________, condensate temperature _____°F

make up water requirement __________.

8. Domestic Hot Water System

a. System Fuel ____________________

b. System Type

Storage ☐ Tank Capacity (gallons) __________

Demand/Instantaneous ☐

Circulating Tank ☐ Tank Capacity (gallons) __________

Other ____________________

c. Capacity (Btu/hr, Kwe ____________________

d. Hot Water Supply Temperatures: ______°F, ______°F

e. Monthly Water Consumption (gallons/month) ____________

9. Process Heating System

a. System Fuel Source ____________ Heat transfer Medium ________
(coal, oil, electric) (steam, hot water, etc.)

	Use	Heat Load (Btu/hr)	Process Temperature (°F)	Use Factor (Hr/Day)
1.				
2.				
3.				

10. Condition of Energy Systems

Are the existing building electrical, space conditioning, domestic hot water and process heating systems performing acceptably? If not, list types of problems being experienced:

a. Electrical ____

b. HVAC system ____

c. Domestic hot water system ____

d. Process heating system ____

11. Critical Power Requirements

a. What are your critical power requirements?

b. Type of equipment serviced by redundant power supply.

c. Description of present backup generation equipment.

Manufacturer		
Rating (KW)		
No. Units		
Fuel Supply Type		
Fuel Storage Capacity		

d. Any special requirements on quality of power other than that typical of present electric utility service?

12. Retrofit Consideration

a. Are there any obvious retrofit problems?

b. Location of nearest natural gas line? ______________________________

Supply pressure available ______________________________

c. Distance between proposed fuel cell location and thermal interface.

____

____

13. Electric Billings Information

a. Utility Company ______________________________ Rate Schedule __________

b. Demand Charge ($/kw) ______________ Energy Charge (¢/kwh) __________

c. Fuel Adjustment Charges ______________________________

Billing Period From	Billing Period To	KWH*	KW Demand*	Cost
Annual Totals				

* Measured Electricity used for ______________________________

14. Natural Gas Billing Information

a. Rate Schedule ____________________ Charge ($/MCF) ______________

B. Fuel Adjustment Charges ____________________________________

Billing Period From	To	MCF	Cost
Annual Totals			

Measured gas used for ____

____

15. Other Fuel Billing Information

a. Fuel Type (Oil, Coal, LPG) ______________________________

Billing Period From	Billing Period To	Quantity	Cost
Annual Total			

Measured energy used for ______________________________

____

16. a. Heating Season Degree Days (65°F Reference) ______________

b. Cooling Season Degree Days (75°F Reference) ______________

17. Simplified one-line diagrams for the thermal and electrical energy systems.

a. Existing system.

b. Existing system with fuel cell interfaced.

18. Map or layout of Air Force base complex with site/application identified.

*USGPO: [illegible]